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THE TRANSACTIONS OF THE FUEL CONFERENCE

WORLD POWER CONFERENCE

LONDON

September 24—*October* 6

1928

VOL I

THE COAL INDUSTRY

THE OIL INDUSTRY

With a Foreword by

C. H. LANDER, D.Sc. C.B.E.

LONDON

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VOL II COMPOSITION, CLASSIFICATION, PREPARATION, STORAGE AND HANDLING OF GASEOUS FUELS AND THE PRODUCTS OF THE CARBONISATION INDUSTRY; UTILISATION OF FUELS FOR STEAM GENERATION AND THE PRODUCTION OF ELECTRICITY; UTILISATION OF FUELS, INCLUDING ELECTRICITY, FOR INDUSTRIAL FURNACE WORK

VOL III UTILISATION OF FUELS, INCLUDING ELECTRICITY, FOR DOMESTIC PURPOSES; LOW-TEMPERATURE CARBONISATION; PULVERISED FUEL; INTERNAL COMBUSTION ENGINES; TRANSMISSION OF POWER; WASTE HEAT RECOVERY; PEAT; POWER ALCOHOL; TRAINING OF FUEL TECHNICIANS; ECONOMIC POSSIBILITIES

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FOREWORD

THE World Power Conference differs in several important particulars from most specialist or technical conferences. In the first place, it not only brings together those whose work is associated with specialisation in any of the various fields connected with the generation, distribution and utilisation of power in any form, but it also allows of their collaboration and closer contact with business men through discussions of the most recent technical developments and practical experiences connected with the subject. Naturally in such discussions considerable importance is attached to the financial and economic aspects of the problem. In the second place, the World Power Conference organises meetings to which are invited statesmen, economists, and others whose daily occupations do not usually bring them closely into contact with power problems, and so enables the general public, which is otherwise frequently seriously misinformed on these matters, to be instructed along sound and accurate lines. By such means it is hoped to promote a better understanding of certain vital questions which affect fundamentally the economics and administration of all countries.

At the present time, by far the greater proportion of the World's power (which must be held to include heat utilised in any form) depends upon fuel for its generation. The British National Committee was therefore entrusted by the International Executive Council of the World Power Conference with the organisation of a sectional conference on fuel problems, which was held in London in 1928.

The meeting was probably the most comprehensive which has ever taken place on the subject. Attended as it was by delegates from forty-eight nations, it cannot have failed to assist in promoting that international good feeling so necessary to a continuation of civilisation in its present form. On the material side, fuel is the foundation of the dominance of mankind, and the necessity for intensive study of its constituton, utilisation and conservation is emphasised by the fact that the stores of fossil fuels so generously supplied by nature are by no means inexhaustible. The fuel resources of different nations vary in nature and amount, but many of the problems involved in their more efficient utilisation are general, and it is to the common advantage that the results of study, experiment and experience should be pooled. From this point of view alone the Fuel Conference was more than justified.

The national importance of fuel in Great Britain requires no emphasis. In the past, the great coal industry which grew up out of plentiful and easily-won deposits, together with industries such as iron and steel, which depend essentially upon cheap coal for their success, have contributed in great measure to the commercial prosperity of the British Isles, and it is vitally necessary that the position of these industries should be restored.

The present century has witnessed the growth of a competitor to coal, and great Britain has become to some extent handicapped by the fact that her large requirements of oil have all to be imported from overseas. In this handicap, of course, she is not alone, but it behoves her, and other countries similarly placed, to spare no effort in seeking means to overcome it.

The Fuel Conference (1928) differed in several ways from previous meetings dealing with the same subject. In particular, the economic aspects of the problems dealt with were given primary importance; further, most of the contributions were presented through authoritative technical bodies and so came with greater force than if they had been merely individual expressions. The papers were suitably grouped into a number of separate sections, in each of which was prepared a general report embodying the more important features dealt with and outlining the main points for discussion. In this way the time available was utilised to the best advantage, and the proceedings of the Conference present a useful, though necessarily imperfect, picture of the trend of development in fuel problems throughout the world.

Of the many points emphasised during the discussions, one of the most important was the desirability for common agreement on nomenclature and units. The question of international standards for the sampling and testing of fuels is one of great difficulty, but some attempt should be made to arrive at agreed methods, which would, besides rendering more easy the translation of experimental work between one country and another, tend also to facilitate the commercial relations between fuel exporting and fuel importing countries.

According to our present knowledge, coal forms by far the largest store of the world's fuel, and the bulk of this coal is consumed in the raw state. The conditions necessary for efficient combustion are well understood, and modern developments largely take the form of mechanical appliances designed to give effect to these conditions. The use of coal in the powdered form is rapidly developing, although at present there is taking place a battle between the bin-and-feeder system and the unit system. Until comparatively recently the unit method was considered suitable only for small installations, but it is now being applied to large boilers also. Great interest is being taken in the question of firing marine boilers by pulverised fuel, but no actual contribution to our knowledge of the subject was made at the Conference.

One of the most serious objections to the use of powdered fuel is the fine flue dust which is apt to be blown out of the chimney and settle upon surrounding property. It was generally agreed that electrical precipitation provides the most satisfactory remedy, but it has the disadvantage of high initial cost and also requires comparatively large spaces for its installation. Here again, in connection with pulverised fuel, arises the necessity for international agreement in regard to standard nomenclature for screening.

The possibilities of cleaning coal prior to its use either in the raw

state or as a raw material in the carbonisation industries, are continually acquiring increased significance. The consequent amelioration of dust trouble in powdered fuel installations is only one of the many examples of the advantages which would be achieved by such treatment. A disadvantage attending the older method of washing by water lay in the fact that the resulting product required drying to bring it into the most suitable state for many applications, but an alternative to washing is coming forward in the dry cleaning of coal, some large installations of which are now in operation both in Great Britain and abroad.

Although the gas and metallurgical coke industries have now behind them a wealth of experience extending over many years, useful discussions and papers bearing on their refinement and improvement were included. The question of co-ordination and unification; the utilisation of coke-oven gas and the development of industrial gas sales; the production of solid smokeless fuels, whether by high or low temperature methods; and the application of the results of research work; are all subjects upon which depend the development of these important industries to a stage at which they will form national assets of even greater importance than at present.

Much still remains to be done in replacing raw coal by the products of its scientific treatment, and the Conference was fortunate in having presented to it, for the first time, the results of a large scale experiment on the carbonising of coal as a preliminary to its use in an electricity station.

The question of blending of coal for specific purposes is of the greatest interest and one upon which knowledge is rapidly accumulating. Scientific blending upon a large scale is making rapid headway as a means of supplying metallurgical coke of good, and still more important, of uniform quality. For the production of a smokeless solid domestic fuel blending appears likely to furnish a solution to many difficult problems. It has already been demonstrated, for instance, that by the use of suitable blends in standard high temperature carbonising plants a satisfactory smokeless fuel for domestic purposes can be produced by shortening the carbonising time to two-thirds the normal.

So far as liquid fuels are concerned, by far the most pressing problem is that of motor spirit, the consumption of which is stil increasing rapidly. The influence of the extension of cracking processes towards augmenting the supply of gasoline is important, although the development of the heavy oil engne will possibly tend to reduce the present price difference between motor spirit and heavy oil fuel, and so react upon the economics of the cracking process. The relation between the quality of motor spirit and its behaviour in particular engines is one which requires further study on the fuel side, although, as Mr. Ricardo has pointed out, there is to-day a tendency for the designing engineer to shift the burden on to the shoulders of the chemist and to demand of fuel dopes what ought to have been provided for by engine design.

Of alternative fuels to petrol, power alcohol has in the past received much attention. The subject was dealt with in Section S, when it was concluded that while it may be possible to produce alcohol on a small scale to meet local requirements where conditions are favourable, petroleum will continue to be the main source of liquid fuels for internal combustion engines.

The above are only a few of the important questions upon which light has been thrown by the papers and discussions of the Conference. As to how far the World Fuel Conference will bring about changes of advantage in the world's fuel economics, time alone can tell. The proceedings, however, form a mine of information and should undoubtedly have a prominent place upon the shelves of all those interested in giving further momentum to the present world-wide movement for a better utilisation of fuels of all kinds.

C. H. LANDER,

Chairman, Technical Committee,

FUEL CONFERENCE, 1928.

FUEL CONFERENCE, 1928

OFFICIAL OPENING AT THE IMPERIAL INSTITUTE

The Official Opening Meeting of the Fuel Conference, 1928, was held in the Great Hall of the Imperial Institute, South Kensington, London, S.W.7, on Monday, September 24, 1928. The President, the Most Hon. the Marquess of Reading, G.C.B., G.C.V.O., G.C.S.I., G.C.I.E., P.C., who presided, and was supported by the heads of delegations and members of the Executive Committee, accorded an official welcome to the delegates (who represented 48 countries), and the Rt. Hon. Sir Robert Horne, M.P., delivered the Opening Address.

The President said it was his duty—and a very pleasant duty—to extend to all the delegates a most cordial welcome to the Conference and to this country. The purpose of the meeting was to initiate a very important Fuel Conference. It was somewhat difficult, particularly for one who was not a scientist or a technician, to envisage all the possible developments of fuel and their application to industry, commerce, and indeed, to the household, but in his position as President of the Conference he had had the advantage of reading and studying various papers on the subject, and he was enormously impressed, as everyone must be who tried to understand the great value of development in fuel throughout the world and the importance of it to the prosperity of nations. Fortunately, this Conference was a world Conference on fuel, and he believed he was justified in observing that it had brought together representatives of nearly all nations. There were forty-eight nations represented, and about 170 papers were to be presented, so that the delegates would have the opportunity of hearing many valuable and important discussions. We in this country were particularly pleased that the various nations of the world had sent to the Conference distinguished representatives, who would speak with authority, and who had established reputations not only in their own countries but also in others, where the developments of fuel technology were watched with always increasing interest. That the Government of this country appreciated the character of the Conference was proved by the fact that the President of the Board of Trade had interested himself in it, and that there would be a Reception of the delegates by the Government.

The delegates at that meeting were specially fortunate in that the opening address would be delivered by Sir Robert Horne, a gentleman with a distinguished reputation not only in this country but in others. It would be a work of supererogation to introduce him to the meeting, but perhaps he (the President) might be allowed one passing reference which made a special appeal to himself. Sir Robert was one of those members of the profession of the Law who had chosen to leave it when he was one of its ornaments, and had devoted himself to other realms which he had since conquered. He had transferred himself into the activities of finance and industry—banking, insurance, transport in all its phases, metals and a variety of other spheres, and had proved that, just as in his early days at the Bar he was able to master his briefs, so at the present time he was able to acquire dominion over whatever business he undertook, and to impress his views upon the public.

The President then called upon Sir Robert Horne to address the meeting.

The Rt. Hon. Sir Robert Horne, M.P., said it was a great privilege to him, and one of which he was very proud, to have the opportunity of delivering the first address to this Conference; but, at the same time, he did so with supreme timidity and diffidence. Indeed, he would scarcely have had the audacity to do so were it not that he recognised that the theme with which the Conference had to deal was one just as interesting to the ordinary man as to the technician. It was true, of course, that if the man in the street were merely to scan the titles of the papers which had been prepared for the Conference, he would be repelled by the technical terms used and by the menacing phrases with which the mysteries of the subject seemed to be surrounded. But at the base of everything there remained the fundamental fact that the problem to be discussed at this very important Conference was that of making the most economical use of our fuel, and thus stated it was plain that the subject came very close to the daily life of the ordinary citizen, confronting him both on his hearth and in his business. Indeed, it would not be an exaggeration to say that no assembly of scientists had ever come together to discuss a matter more relevant to our common everyday life, nor had there ever been held a technical conference from which there might flow so many practical consequences vital to the future progress of the world. It used to be adduced, as the pre-eminent example of the technical scientist's outlook, that a famous mathematician from Cambridge, after having devised a theorem, had said: "And the best of it is that it can never be of any use to anybody for anything." To-day, on

the other hand, it seemed that the proudest boast that science could make was that it had conferred great benefits upon the simple people of the world. The branch of science which was represented at this Conference could make a great claim in that regard, and he was sure that the discussions would conduce very greatly to the future progress of the people of the whole world.

There were two remarkable features of the Conference which were well worthy of observation, one of which had been referred to by the President. The universality of the interest in its purpose was demonstrated by the fact that forty-eight countries were represented, and that twenty of these countries had submitted papers of very great importance, giving the world the advantage of their experiences. Another circumstance, which he believed to be unique, was that there were assembled at the Conference representatives of industries which were very often regarded as antagonistic to each other, and which certainly adopted a somewhat detached attitude to each other. They were to-day prepared to exchange views upon the subjects in which they were all interested, and to put into the common stock the knowledge which they had gained through their researches. The industries he referred to were those of electricity supply, electrical engineering, coal, gas and oil, and of chemical manufacture, all of which, instead of conducting their discussions, as was customary, within a domestic enclave, were attending the Conference in order to exchange views as to the best uses to which the various fuels could be put. That was a feature of the Conference which was most striking, and one which he believed would conduce greatly to the fruitfulness of the discussions.

This Conference was the third organised by the World Power Conference. The first meeting was held at Wembley in 1924, when electricity in all its phases was discussed. The second was at Basle, in 1926, when the main theme of consideration was water power. The subject of the present Conference was the use that could be made of fuel in the production of power. The importance of the subject could scarcely bear exaggeration, because fuel was the foundation of the industrial prosperity of this country. There were some countries, such as Canada, favoured by nature with water power which they were able to use to enormous advantage, but there were others, such as Great Britain, in which fuel must always be the source of power. Fuels of all kinds were within the ambit of the discussions at this Conference, but of the 170 papers tendered two-thirds dealt with coal, and he did not think he would be committing an error in saying that the main subject of the investigations was going to be the best method by which we could exploit

every economic value that could be obtained from coal. As showing how vital was this question to the citizens of this country, Sir Robert said that one-twelfth of all our population depended upon the coal industry for their livelihood, and that four-fifths of the volume of our exports, and one-tenth of their value, normally consisted of coal. Not only was the whole of our industrial fabric built upon coal, an ample supply of which was available in this country, but the coal which we exported, by reason of the freights which it afforded the shipowners, enabled us to buy at lower prices the food and raw material which we required to import from abroad. It would be appreciated, therefore, how vital was this subject in Great Britain.

The coal industry of this country was in a condition of depression, and it had been predicted that coal had passed its zenith, that it would be superseded by oil, and that never again would coal be developed in this country to the extent that it had been in the past. He, personally, had never accepted that view. The modern prosperity of Great Britain was created by coal, and in his view it would be saved by coal; but only by adopting improved and more economical methods of using it, such as were foreshadowed in some of the papers submitted to the Conference. Of all the extravagances of which we in this country had been guilty, the greatest was that of waste of coal; the amount of wealth which had been sacrificed as the result of our inability to conserve our coal was entirely beyond computation. Even to-day in this country, three million tons of potential fuel were being emitted into the air in the shape of soot each year, which not only involved a great loss of heat and power, but also resulted in polluting the atmosphere which we breathed, robbing our industrial districts of twenty per cent. of their sunlight, and creating conditions which were inimical to the health of our people. The pouring of raw coal in its crude state into furnaces and domestic grates must now be recognised as a tragedy from which we must find a way of escape. He rejoiced to think that we were now on the way towards a solution of that problem, and he for one looked to the eminent men who were attending the Conference to enlighten us as to the exact position of research and achievement to-day, to define the principles on which we had made progress in the past, and to indicate the lines upon which we should succeed in the future.

For himself, and speaking with no special knowledge, he ventured to say that his main hope, in this country at least, was in the development of processes of low-temperature carbonisation. In the past many premature claims had been made by those

concerned with the various processes, with the result that a large number of people had become sceptical because there were no plants yet in operation on a large scale. Sometimes the blame had been placed where no blame was due. Even the pacific scientist was inclined to say sometimes that the business man lagged behind the opportunities which the advance of science afforded him, and the public, taking up that kind of suggestion, very often blamed the industrialists in this and other countries for lack of initiative. The case of low-temperature carbonisation was a very good example. For a long time we had had before us a very beautiful laboratory experiment. From a ton of coal we could extract from 14 to 20 gallons of a tar or thick oil, whichever we chose to call it, and between 3,000 and 5,000 cu. ft. of gas, from which, by scrubbing, we could obtain $1\frac{1}{2}$ gallons of a light spirit and in addition a residual semi-coke which could be burned in domestic grates. He had listened to many speeches in the House of Commons in the course of which it had been asked "Why is not every coalmaster in the country carrying out these operations to-day, for the benefit of the coal mines and to the advantage of the country?" Speakers seemed to forget that a laboratory experiment was no test of commercial success, and that unless we could repeat the experiment on a large commercial scale, so as to yield a profit on the money required to be invested in the operation, nobody was going to throw away his resources in carrying it further. There was always money in a country such as ours for schemes which looked really favourable, and in connection with low-temperature carbonisation a vast amount of enthusiasm and a vast amount of money had been expended. Something like 400 processes had been tried in different countries. The difficulty had been to produce a residual fuel which could easily be used both industrially and domestically, and whose value, along with that of the by-products, would be sufficient to cover the cost of the process and the original raw material. That, after all, was the test. He believed it could safely be said that at long last we were emerging from the experimental stage with regard to these processes, and were entering the industrial and commercial stage in the case of at least some of them. In Germany they had succeeded in carbonising brown coal at low temperatures and burning the residual fuel under the boilers of central stations in connection with high-pressure transmission systems; and, as a result, large areas of Central Germany and the Ruhr were being supplied with electricity, while the surplus gases obtained had been used in the chemical industry. It might be said, so far as Great Britain was concerned, that that did not settle the

matter, because brown coal, and, indeed, all the young coals of the world, were much more amenable to treatment by such processes than were the bituminous coals of Great Britain. At least one of the electric supply companies in this country, however, had been applying such a process to bituminous coal. It had been carbonising a low-grade coal at low temperatures and burning the residual fuel under boilers, and it had been able in effect to pay for the bulk of its raw material with the revenue obtained for the by-products. As a result, it had been able to produce electricity at a very low price. Such developments gave ground for great hope. If they were carried on, we should in the end obtain cheaper power, and at the same time there would be a greater use for coal, conferring advantages at once upon our manufacturers and upon those at present in distress in the coalfields.

Dealing with other methods of treating coal which were creating great interest, Sir Robert mentioned the process for the hydrogenation of coal at high pressure. That process, he said, was generally associated with the name of Bergius, but he believed it began long ago by the experiments of the French chemist, Berthelot. The hydrogenation process produced six times as much liquid fuel as was produced by low-temperature carbonisation, but no residual coke. What would be the result of the application of these processes in Great Britain one could not tell. Their application in Germany had been so successful that very large sums had been invested in plant and equipment by a very strong organisation there. In this country they had not been tried out, and it was very doubtful whether the same results would be obtained with our bituminous coal as could be obtained with the German lignites, because bituminous coal was much more difficult to deal with. Again, one could not say that the oil so produced would be able to compete in the market with the oil produced from wells, especially in the present time of cheapness. It was quite possible, however, that in a country with a tariff against imported oils the native product could be sold as against the imported product; and, in any event, a country which was able to make oil by the hydrogenation process was in a position of independence, and would be able to create its own supplies if at any time circumstances arose as the result of which the stocks of the outer world were cut off.

Another fascinating topic of speculation was the steady development of pulverised fuel, and he regretted that Great Britain was somewhat behind some other countries in connection with this matter. The developments which might arise from it were, in his view, infinite. It was perfectly plain already that we could get

much more calorific value out of the coal when pulverised than when using it in its raw state; the difference was probably as great as 20 per cent. Further, the utilisation of coal in this form would enable us to make use of low-grade coal which otherwise would not be used. This process was also linked with that of low-temperature carbonisation, for the reason that pulverised residual fuel from the low-temperature process had advantages in certain circumstances over pulverised coal. Pulverised fuel was beginning to be used in ships for raising steam, and steamers were designed to carry equipment for pulverising coal before feeding it into the furnaces. The suggestion had been made from time to time that the coal should be pulverised on shore and blown by machinery into the ship's bunkers, but the trouble was that pulverised coal was subject to spontaneous ignition, so that the carrying of the coal in pulverised form involved grave risk of fire. It was claimed for the fuel produced by low-temperature carbonisation, however, that it was not subject to this disability when pulverised, and that it could be carried in the bunkers of a ship without fear of spontaneous combustion.

Other economies, too, in the use of fuel were in the way of being achieved. Waste heat from coke ovens, blast furnaces and steel furnaces, was now being turned to industrial use, and in Germany and France great advances had been made in this direction. There were also methods of producing synthetic liquid fuels; and, as we had learned from a recent report of one of His Majesty's Commissions, there was a prospect of establishing great centres from which gas could be distributed over wider areas than had ever been thought of before.

The developments he had mentioned, said Sir Robert, were sufficient to show the vast importance of these topics—topics which in any ordinary time would be of absorbing interest, but which were at present vital to a world whose wealth and resources had been so catastrophically dissipated during the conflict from which we had recently emerged. The present moment was fateful. We were all looking for something to carry us out of the rut of our post-war distresses and again fill our breasts with hope. The coming together of the representatives of so many nations, some of which were recently locked in deadly conflict, to combine in one common effort to solve their mutual problems in order to confer benefit upon all, was an inspiring picture, which was enough to stimulate our energies and enliven our spirits. In a scientific conference such as this, jealousies, national and individual, tended to disappear, and those who were accustomed to pursue knowledge for its own sake, and not merely for personal gain, were much more

ready to exchange ideas than were those whose lives were spent in the ordinary over-reaching processes of barter. Even in the competition of commerce, however, men had begun to learn that frequently there was more to gain by communicating than by concealing the methods by which success in any particular business was being achieved. If everyone attending the Conference was prepared to give of his best for the common benefit, the results which would be achieved by their united deliberations might well have a most potent influence upon the prosperity of the world.

REPLIES ON BEHALF OF PARTICIPATING COUNTRIES

General Direktor Dr.-Ing. Eh. C. Köttgen (Germany) replied on behalf of the nations of Continental Europe. He regarded it as a great honour, he said, to have the opportunity to reply, and he and his friends esteemed it as a special token of confidence and friendliness. They were grateful to Great Britain for having invited the whole world to this important Conference. The number of delegates, and the quantity and significance of the papers contributed, was evidence of the world's admiration for the initiative of England in furthering technical and economic progress. It was England which, in 1924, had tried to unite all nations in the World Power Conference. This important meeting of 1924, which was well organised, had brought all nations into co-operation, and the results were valuable. That Conference was the foundation of further co-operation. At the Sectional Meeting at Basle the problems of water power were discussed, and Basle, situated at the base of the mountains of Switzerland, was just the right place in which to discuss water power. The present Sectional Meeting in London was concerned with fuels. A son of England, James Watt, had given the world the steam engine. Nature had favoured this country with an abundance of coal, and this country had had the privilege of furnishing other countries with this indispensable source of energy. England, therefore, was the proper place in which to discuss fuel, and this careful selection of the countries in which to hold the different meetings was proof of the wise management of the World Power Conference, and of Mr. D. N. Dunlop, the Chairman of the British National Committee. Mr. Dunlop's thoroughness was also evidenced by the selection of subjects for discussion. Water power and fuel were the sources of energy; hence the necessity for discussing these matters first.

Dr. Köttgen welcomed the spirit of co-operation which was now manifest. It was in this spirit, he said, that England had arranged the first World Power Conference; in this spirit the work had been continued, and in this spirit the delegates to the present Conference had met. By mutual exchange of knowledge and mutual assistance in the search for new ways and methods, the general level of ability would be raised. The able man had always the chance to take the next step forward. After again expressing thanks to Great Britain for having arranged the present Conference, he voiced the hope that the discussions would be conducted in the co-operative spirit which had been manifest heretofore, and that everyone would give of his best for the benefit of all.

Mr. O. C. Merrill (U.S.A.), responding on behalf of the U.S.A. and South America to the cordial welcome extended by the British National Committee, said that those who had had the privilege of attending the World Power Conference in 1924 well knew the meaning of British hospitality. The delegates had visited England in 1924 to assist in the inauguration of a new international undertaking, a co-operative movement for the interchange of information and for the comparison of methods of development and utilisation of certain of our natural resources. That that proposal was a practical one, and that it met a real need, was amply evidenced by the response from all parts of the world to the British Committee's invitation in 1924, and by the response to the invitations to attend the two subsequent Conferences.

There was much of real value that an organisation such as the World Power Conference could accomplish. Fundamentally, progress in any scientific activity depended on knowledge of the facts, and they were only partially known to-day. The individual delegates could assist in the collection and compilation of the facts, and the Conference served as a place for the discussion of the application of the facts to practice, and for the interchange of ideas; in addition, it could, when desirable, act as sponsor for that research which must always precede improvements in any sphere. But in seeking improvement, we must not aim at too much uniformity. Physical circumstances, political and social institutions, and in fact, national temperaments, must also be taken into consideration even when dealing with so materialistic a matter as the utilisation of our fuel resources. If we were to avoid the dull level of a standardised world we must realise that industry, as well as science and art, must proceed in conformity with the special requirements of each country and under the impulse of its own national genius. Those taking part in Conferences such as this

were necessarily directing their efforts to securing a more efficient use of material resources, but merely material objects should not be their ultimate goal. They should realise that behind the work of such Conferences, behind the work of the scientist and the engineer, there was an ultimate object other than the material. The real object of such Conferences was, in fact, to secure a more efficient utilisation of our resources, not for the special advantage of any nation or any group or class, but for the general benefit of all our people. We could not read history, be it political, social or economic, without realising that always man had struggled to be free—free from the menace of nature, free from the oppression of his fellow men, free from the burden of distress and the fear of poverty, free to live and act and think, limited only by the obligation to accord a like freedom to others. Whilst those attending Conferences such as this dealt with only a very limited number of the factors which entered into this matter, they were nevertheless factors which, if properly controlled and directed, were perhaps more than any others in modern industry capable of bringing about the economic freedom of the individual, and it was only through economic freedom that that larger freedom which was the ultimate object of human society could be attained. The work of this and of other Conferences would have real and lasting value to the extent that the ultimate end and the conscious purpose was social.

Mr. B. F. Haanel (Canada) responded on behalf of the British Dominions, and said that he did so with particular pleasure because he had had the honour and privilege of attending the First World Power Conference, in London, in 1924, and since that time had had the opportunity of examining the benefits which that Conference had conferred upon the world. Every delegate he had spoken to, he continued, appeared to be of the same opinion regarding the value of these Conferences, and so pronounced was this opinion that one speaker alone could voice the sentiments of practically all the countries assembled. That opinion was that not only had the World Power Conference contributed most valuable aid in the furtherance of all projects relating to power and the development of fuel resources, but it had proved a valuable agency in promoting goodwill between the scientists, fuel technologists and engineers of the various countries of the world. The British Dominions were separated by thousands of miles and, therefore, the scientists and technologists in the Dominions had not hitherto enjoyed facilities for meeting either their own cousins in Great Britain or their colleagues in Europe and Asia. These Conferences, however, afforded such facilities, for in ten days or less one was able to meet

and to become acquainted with the representatives of 48 countries. By what other means could this be accomplished? They all had their fuel resources, their fuel problems and their technical organisations for conducting fuel research; and, while their work was greatly facilitated by free discussion in and out of Conference chambers, the greater benefit resulting from the forming of friendships through personal contact was also bestowed upon them. In this manner these Conferences served as powerful agencies for the establishment of world peace, for the friendships formed and the goodwill established would spread until nations were embraced and conquered.

The men assembled at the Conference were the silent workers, who would never strike when circumstances aroused their displeasure, but who continued plodding on. They were the representatives of the men who held the destiny of the world in their palms, inasmuch as they were responsible for keeping the wheels of industry moving smoothly and continuously, and for the maintenance of systems of transportation, whether by land, sea or air—a temporary cessation of which would be disastrous. Further, they were responsible for the employment of the countless numbers of skilled and other workers, for this was a scientific age, and one, therefore, which must be maintained by those scientifically trained. He had been wondering whether it would strain the imagination unduly if one were to predict that the greatest of all the results achieved by these Conferences might be the birth of the real "Dove of Peace" for which the eyes of all classes of humanity had been so eagerly watching for generations. He had noticed a great change in the relations between men in different countries during the last four years. Men who, before the World Power Conference of 1924, were real strangers to each other, were now exchanging their knowledge freely, giving each other the opportunity of benefiting both by their successes and their failures, and giving advice.

Finally, Mr. Haanel expressed the regrets of the Chairman of the Canadian National Committee of the World Power Conference, Dr. Charles Camsell, that he was unable to appear at the Conference in person. He was certainly there in spirit, said Mr. Haanel, for there was no other man of his acquaintance who had the interests of the proper development of fuel resources so much at heart.

Dr. M. Kamo (Japan) responded on behalf of the Asiatic nations. He rejoiced that representatives from the various countries of the world had again met at the World Power Conference and would discuss fuel problems, which were of such vital importance to life and progressive prosperity of every nation. He was also very pleased to note that the Japanese contribution to the discussions

was fully up to average. In a book which he had read recently the statement was made that the nation which controlled oil could control the world. That was perhaps too violent a statement, but it was certain that a nation with an ample supply of fuels, whether oil or coal, black or brown, was in a very advantageous position. The rapid increase in the prosperity of Great Britain, for instance, particularly during the 19th century, was based on her coal supplies, which were not only abundant, but were of wonderful quality. It was true that for the moment the British coal industry was struggling against adversity, but he predicted that the difficulties would be overcome. The results of this Conference might provide just that impetus which was needed to overcome them. The object of scientists and engineers, he said, was to improve the condition of all peoples and to add to their comfort and enjoyment. This Conference, composed of over 1,500 interested and well-informed individuals, could not fail to achieve success in that direction. In the name of the Japanese National Committee, and on behalf of all Asiatic nations, Dr. Kamo thanked the President for his cordial welcome of the delegates, and Sir Robert Horne for his inspiring address. He also expressed thanks to the officials, headed by Mr. Dunlop, who had worked so hard to ensure the success of the Conference.

Finally, Dr. Kamo reminded the delegates of the World Engineering Congress and of the Sectional Meeting of the World Power Conference, to be held in Tokyo in October and November, 1929, and extended to all nations a hearty invitation to send their delegates. The Government of Japan was giving the organisers a generous subsidy, and the citizens were looking forward to greeting many engineers from every country in the world. Japan, he said, had much scenic beauty and many things of great historical interest, and a programme of visits to these places of interest and pleasures had been prepared in addition to the programme of the Conferences.

This concluded the business of the meeting.

BANQUET

The Banquet was held at the Connaught Rooms, Great Queen Street, London, on Monday, September 24, the Most Honourable the Marquess of Reading, G.C.B., G.C.V.O., G.C.S.I., G.C.I.E., P.C. (President of the Conference) in the Chair.

The Toasts of "His Majesty the King" and "The Sovereigns of the Kingdoms and the Presidents of the Republics Represented" having been duly honoured,

The Rt. Hon Sir Philip Cunliffe-Lister, K.B.E., M.C., M.P. (President of the Board of Trade) proposed "The Fuel Conference" and welcomed the World Power Conference once again to London. He recalled that it was four years ago that the first meeting of the Conference was held during the Wembley Exhibition, but although that was a valuable and representative Conference, the present Conference was far more representative, because no fewer than 48 countries were represented, and he knew of his own knowledge that every fuel interest in Great Britain, direct and indirect, was represented. The Conference demonstrated how world wide was the interest taken in fuel problems and also that at last it was being realised that it was good business to pool knowledge, not only within industries but as between one industry and another, and last but not least, as between one country and another. We were learning that general progress meant general prosperity, and in no field was that truer than in the field of fuel production, fuel consumption and fuel research. Everywhere to-day producers of fuel and manufacturers of all commodities were facing the problem that unless they could find new outlets for what they produced, they were up against an excessive capacity to produce and to manufacture. In every country efficiency in fuel consumption was an important factor in industry and in transport, on sea and land, and even in the air. It was also an important factor in power production. Was it not true also that in every country scientific discovery and manufacturing efficiency had increased, with the result that greater outputs were being obtained, so that unless there was a much greater consumption in every land it would be impossible to keep the populations fully employed? Not only was it of vital importance for employment that efficiency in the use of fuel should be increased, but it was equally to the interest of the producer and the user of fuel, so that in every coal producing country all these interests must do everything possible to stimulate consumption. The more progress there was made of this kind the less would be the cut-throat competition between different countries. Whilst absurd under-cutting was bad not only for the coal industry but for other industries in the long run, and should be eliminated by efficient organisation in the coal industries themselves, it was even truer to say that no far-sighted coal owner to-day looked to combination as a means of raising prices in a static or diminishing market. That was not vision, and the coal owner must look to combination as giving him an opportunity of working not against, but in collaboration with those industries which consumed his products in order to increase his sales and enlarge his markets.

Taking a few examples, Sir Philip Cunliffe-Lister first referred to

the classification, cleaning and grading of coal. That surely, he said, was equally to the interest of the producer of coal and the consumer. The consumer desired to know what were the characteristics of the coal he was getting. He wanted to know what was the calorific value and the ash content, and he wanted to be assured that he would always get an uniform quality. Surely it was to the interest of the producer to see that the consumer got what he wanted in that respect. The user did not wish to buy coal with a large ash content. Referring to pulverised coal, and speaking on the advice of those much more qualified to express an opinion than himself, Sir Philip remarked that pulverised coal has a great future, not only on land but on sea, but those who knew best and had most faith in the process realised that progress must necessarily be slow at first, because the process must be tested by full experiments on a practical scale. In the use of pulverised fuel on ships he was pleased to say that co-operation already existed to the full in this country. Ship owners, ship builders, engineers and coal owners, were all co-operating together in important experiments which already justified him in saying that they were full of promise and showed some measure of fruition. That would never have been obtained but for combined effort on the part of all who had a common interest in the coal industry. Again, was it not to the common interest of all coal owners and those who were responsible for electric supply, always to keep in the closest touch? He was by no means sure—experience would prove it—that some considerable contribution would not be made to the electric supply of this country when the coal mines were linked up to the great grid system, so that low-grade fuel could be burned at suitable coal pits for the generation of electricity and its supply to the grid system.

One other example might be taken of the advantages of combination not in the coal industry, but outside the coal industry, as tending towards greater production in this country. The interests of the fuel industries impinged at once upon other industries such as gas undertakings, the chemical industry and the iron and steel industries. It was a very fortunate circumstance that the publication of a most valuable report by the National Fuel and Power Committee, which he appointed some eighteen months ago, should have been made at the time the Conference was meeting. There was one practical and valuable suggestion made in that Report to which he had devoted immediate attention. The Committee suggested that an inquiry should be carried out into the use of surplus coke oven gas and that it might be worth while for the investigation to be put in hand as regards some wide industrial area, such as that between the Mersey

and the Humber, to see whether all gas undertakings in that area could not take a supply of gas from the coke ovens existing or which might be developed in the future. It was an inquiry well worth undertaking. It would be necessary to ascertain what was the amount of coke gas obtainable in the area, what was the actual demand to-day, and the prospective demand and supply in the future. It would be necessary to consider what would be the cost of installing and connecting mains, and further what would be the effect of any such development upon coke production and the market for coke. He was able to say that the Government proposed at once to undertake that inquiry, and in doing so he was certain he could count upon the co-operation of all the interests concerned, coal, gas, coke, iron and steel, and any others that might be affected. In this connection he was going to make one request to these interests. Such an inquiry could only be carried out with an efficient and experienced staff, not a large one but a good one, and in acting upon the suggestion of the Committee his proposal to the industries concerned was that they should supply to the Government the necessary staff to conduct that inquiry, for the simple reason that the men most qualified to do this work were engaged in the industries themselves. It would be a national inquiry; and, therefore, he was confident he could rely upon this degree of co-operation from industry. Moreover, he believed it would be found that the staff so provided would, at the end of their special work, go back to their respective companies even more experienced and more able than when they started it.

Continuing, Sir Philip spoke of the great progress being made and the openings now available for trained fuel experts. Such men, he said, although they might command high salaries, quickly paid for themselves by the very large savings they made in the operations of the business they were employed in. In this connection he urged a closer association between industrial research and the universities, because this must inevitably result in greater advantage to industry when the men trained in the universities came out and took up their positions. Many of the great industries of the country had been most generous in the endowment of universities in the past, but he was not sure whether they had looked upon this endowment as a liability or an asset. Personally, he believed it could be converted into a valuable interest-bearing asset if industries would only use the universities aright and make use of their own munificence by seeing in the first place that men were suitably trained and afterwards taking them into their employment.

In conclusion, Sir Philip Cunliffe-Lister commented upon the

manner in which the problems of which he had just touched the fringe re-acted upon so many diverse industries and interests. What was done in one country acted and re-acted in every other country, and it was in the knowledge that the Conference met in a spirit of determination to carry out combined work for the general good of the nations of the world that he offered it a hearty welcome in the name of the Government, and coupled with the toast the name of Lord Reading.

The Most Hon. the Marquess of Reading, G.C.B., G.C.V.O., G.C.S.I., G.C.I.E., P.C., responding to the toast, expressed his grateful thanks on behalf of the Conference to Sir Philip Cunliffe-Lister for his cordial welcome and his interesting address. It was, he said, a recognition by Sir Philip, as the Minister mainly in charge of the matters pertaining to this Conference, of the importance of the problems to be faced as regards fuel. Speaking for himself, Lord Reading said that, although he made no pretence to scientific or technical knowledge on fuel, he was not uninterested in the effects that might be produced by the Conference. He was deeply interested in his country and also in international affairs, and for that reason he rejoiced that the privilege had been afforded him of presiding at the Conference and taking part in some of its activities. That it was an accident that he should be in the chair, due to the enforced absence abroad of Lord Melchett, was a matter of regret for the members of the Conference, but to himself it was a real privilege to occupy the present position.

Having considered various aspects of the problems with which the Conference was to deal, continued Lord Reading, he felt he would like to have the opportunity of listening to the paper and discussion seeking to simplify the terms used, so that when men met to confer they would be on common ground and would not discover after much time and labour that they all meant the same thing when they had appeared to differ, due to the use of terms which did not carry to all the same interpretation. The picture presented by the President of the Board of Trade with regard to Great Britain alone, was of absorbing interest, and he would not attempt to recapitulate or reinforce what had been said by the President of the Board of Trade with much greater authority and knowledge than he himself possessed; but at least we could all feel assured that in the deliberations of the Conference and in the results that would ensue, there would be benefit to industries which had such great importance in this country, and which would also affect the prosperity of the world. The Conference was a World Conference, not only a national one, and therefore

valuable advantages should inevitably ensue from its deliberations.

Speaking of the possible conflicting interests represented at the Conference in the various departments of power production, Lord Reading said that he had recently heard that of the power produced in the world at present, 30 per cent. was represented by water and oil, and the remainder by coal, so that there was room still for oil and water. At the same time he hoped that those interested in coal would not lag behind. Indeed, there was a future for all forms of power, and the spirit that imbued the Conference was to seek out the best means of development in all directions regardless of the particular interests of industries or nations to develop the avenues of knowledge and to produce new discoveries, and thus add to the scientific knowledge of the world. By such means cheaper production would be ensured and trade would be developed throughout the universe. No country to-day could afford to disregard the influence of science upon industry. Time was, perhaps, when Great Britain was a little slow in the prompt application of science to industry, but it must be remembered that discoveries in the laboratory were not always immediately capable of producing practical results. The time was, however, rapidly approaching when we should not hesitate to seize upon knowledge produced and tested by research and to avail ourselves of its benefits.

There was, however, another aspect of this question which had impressed itself upon his mind as he had endeavoured to survey the situation as a layman with some experience of world affairs, an aspect which had warmed his blood and kindled his imagination. If in these circumstances he allowed himself to speak with a little more enthusiasm than was permissible amongst scientists and technicians, he was sure he would be pardoned when it was realised that he was speaking from a deep conviction. The impression in his mind was that this World Conference with its forty-eight nations, some of whom were only recently at war, was meeting without regard to political differences and was engaged upon a common object with a common interest and with a desire not so much to add to a particular nation's asset as with a desire to contribute to the benefit of the whole world. It was a great ideal, the effect of which was difficult to catch at first sight. During the Conference the members would meet in social intercourse as well as in the discussion of their problems. Men would come into contact with each other who had failed, perhaps, to appreciate the value of men of another nation. In this way asperities which may still have lingered might be smoothed away. A common interest seeking to develop the prosperity of the world, linked them together and made them all

politicians in the same cause; it made them all co-workers with the same object in view, co-operators in the great world peace which everybody was seeking to perpetuate. He liked to dwell upon this aspect which was, perhaps, especially appropriate at the moment when only quite recently the Pact for the renunciation of war had been signed in Paris, an important step taken in expression of the desire of the world for peace. A common interest was one of the strongest factors for peace. It was an interesting speculation in history to cast one's mind back upon the wars of the past and to wonder how many of them would never have taken place but for the keen competition between nations, and had they all been engaged together in seeking the common prosperity of humanity. With that thought in mind he liked to dwell on the effect of this co-operation as exemplified in the Fuel Conference, because he believed that work of this character laid foundations which in the future would have great effect upon the political world. As one who desired a world peace, he felt that science should no longer be employed in the work of destruction but should concentrate upon construction, and in again thanking Sir Philip Cunliffe-Lister for addressing the Conference and thanking the Conference for giving him the privilege of presiding over it, Lord Reading said he had endeavoured, very inadequately, to express the thought that the ultimate aim for which all must strive and work, so long as they were anxious to do their duty to the world, was to endeavour to lay foundations which would help in the desire for a world peace.

Sir David Milne-Watson (Great Britain), proposing "Our Guests," said it was a toast which really required no words of his to commend it, because he knew it would be received with the utmost sincerity and heartiness. Never had he more regretted than at the moment, the happenings of the Tower of Babel, or wished that there was some common language in which he could say how much we rejoiced to have present so many distinguished friends from all parts of the world; how gladly we welcomed them to London, and how much we hoped that they would enjoy their stay here, and that when the Conference was at an end they would take away with them memories of their visit as happy and as lasting as those which we, their hosts that evening, took away with us after the Sectional meeting at Basle held under the able presidency of Dr. Edouard Tissot.

On the occasion of the first meeting of the World Power Conference which took place in London just over four years ago, we had the pleasure of welcoming the representatives of some forty nations. That evening, despite the fact that they had assembled for a

Sectional Conference only, and not for a plenary session, there were representatives of forty-eight countries present. That large attendance indicated that the Conference was a real force meeting a real need. The saying "All work and no play makes Jack a dull boy" was one which must have a counterpart in some form or another in every tongue, and he confessed that as he studied the Programme of the Conference he felt that even the most greedy searcher after knowledge would find moments of relaxation necessary. The meetings of the World Power Conference had very great intrinsic importance. They also had a significance much greater than at first sight would appear. They had gathered from all parts of the world to discuss matters which were of common interest to all, to hear from scientists and technicians of all kinds the latest advances which had been made towards the solution of each branch of the world's fuel problem and to share one with another the discoveries which science and experience had revealed since the Conference at Basle. Just as in every country there must be rivalry, competition and conflict of interest between those directly concerned with the various branches of fuel production and supply, so as between countries, there must necessarily also be rivalry and diversity of views and interests, but to the great benefit of ourselves and of the world at large these were laid aside at our meetings, artificial geographical divisions disappeared, and we became fellow workers in a great common cause.

From our own point of view the world was now a much smaller place than it used to be, and the interdependence of the various units of mankind which inhabited it was more and more being borne in upon us. No nation was, or could be, entirely independent, and so it was that Conferences such as this were almost a necessary concomitant of the world's progress. They were necessary in our own individual interests and in the interests of the world as a whole. But these meetings had another and wider significance. In discussing what he called domestic problems in a frank and friendly spirit, we learned much of each other's point of view, of each other's difficulties, and thus came to understand each other in a way which must necessarily have a beneficial effect upon our international relations. We all rejoiced that the Pact of Paris had been adhered to by so many nations, and we rejoiced to know that the League of Nations was constantly striving to secure world-wide peace and good-will. He was, however, convinced that no greater impetus could be given to the cause of world peace than by the meeting of men from all parts of the world to discuss common interests. Such meetings were becoming increasingly common and increasingly

important and they must, in the very nature of things, tend to the creation of better relations and better understanding, and to the banishment of any atmosphere of suspicion and mistrust.

Being the Fuel Section of the World Power Conference, we should be discussing inflammable matters, but he had no hesitation in predicting that the only heat which would be generated would be the heat of enthusiasm for our work and the heat required to weld still more strongly the happy bonds which already united us, and if there should be any "waste" heat, let it be used for the softening of the sword so that it might more readily be beaten into the ploughshare. With the toast of "Our Guests" he coupled the names of M. Guillaume, Mr. E. V. Hansen and Dr. Edouard Tissot.

M. Guillaume, Vice-President of the French National Committee of the World Power Conference, was the chief French delegate at the first Conference in 1924. During all his official career he was connected with the Department of Mines in France, and had only recently relinquished the post of Director of Mines. He was also an expert on synthetic fuels and was the President of the National Nitrogen Association. In addition to the great technical knowledge and experience which he brought to the work of the Conference, M. Guillaume had wide experience of international affairs.

In Mr. Hansen we had a President of a National Committee—that of Sweden—and he, too, was his country's chief delegate at the first World Power Conference in 1924. His intimate knowledge of the problems of water supply for power and other purposes culminated in his appointment as Director-General of the Royal Board of Waterfalls, a post from which he had recently resigned, to the great regret of his colleagues. Mr. Hansen also had an international reputation. He had been connected with the League of Nations since 1924, and as an engineer he had been honoured by the University of Dresden. Mr. Hansen was a loyal supporter of the Conference, and to him, as to M. Guillaume, Sir David expressed pleasure at seeing them once more in London.

Dr. Edouard Tissot would be remembered as the President of the Basle Sectional meeting of 1926, the organisation of which under his direction was excellent, and an extremely cordial reception was given to the British and other foreign delegates. Dr. Tissot was Vice-Chairman of the International Executive Council of the World Power Conference, and President of the Swiss National Committee. He was a Doctor of Science; and although since 1907 he had been Director and Managing Director of the Swiss Railway Bank, he had by no means severed his connection with the electricity industry in which he began his career.

M. Guillaume (France) spoke in French as follows :—

En 1924 nous avons applaudi de grand cœur ici même à la naissance de la Conférence mondiale de l'énergie et à l'idée généreuse qui l'avait engendrée.

Nous retrouvant à quatre ans d'intervalle, c'est pour nous un plaisir de constater les résultats obtenus et le succès qui a marqué les différentes manifestations de la Conférence.

C'est surtout pour nous un devoir, et un devoir qui nous est très agréable, d'une part de féliciter les promoteurs de l'entreprise, et tour particulièrement le très distinguè président du Comité exécutif international, Monsieur Dunlop, de ce succès qui dans une très large mesure est son œuvre et celle de ses collaborateurs; d'autre part, de remercier le Comité national anglais de l'organisation si parfaite du congrès qui vient de s'ouvrir et de l'accueil si plein de cordialité qu'il nous a ménagé.

Le nombre des nations représentées ici atteste que la Conférence est devenue véritablement mondiale; nous nous félicitons de voir participer aux congrès des nations qui n'étaient pas représentées à Londres en 1924. Nul doute que l'intérêt des travaux de la Conférence et les résultats à en attendre en soient puissamment accrus.

Pour apprécier cet intérêt il suffit de jeter un coup d'œil sur le programme qui encadres les questions que vous allez discuter dans les prochains jours, Messieurs. Si certaines d'entre elles ont plus d'importance pour les pays producteurs de combustibles, les autres qui concernent la meilleure utilisation de ceux-ci sont capitales pour toutes les nations puisqu'elles tendent à éviter une dissipation de l'énergie, c'est-à-dire d'une des parties essentielles du patrimoine humain.

Certains des problèmes que vous aurez à examiner ont reçu déjà une solution satisfaisante, sinon définitive.

Vous pourrez enregistrer le chemin parcouru depuis quatre ans. La constatation par les congrès des résultats obtenus dont la progression est rapide tendra à provoquer l'extension des procédés qui ont fait leurs preuves.

D'autres problèmes ne sont encore qu'à un stade moins avancé. Ils relèvent encore du laboratoire ou des essais industriels.

L'examen des recherches poursuivies dans les différents pays, l'échange d'idées auquel cet examen donnera lieu, coördinera les efforts, orientera les études nouvelles et hâtera l'heure à laquelle la solution pourra être obtenue. Mais peut-être la discussion des problèmes techniques qui figurent à l'ordre du jour du congrès et les progrès que cette discussion peut susciter, ne constituent pas l'objet unique, je serai tenté de dire l'objet principal de la Conférence mondiale de l'énergie.

Ce qui fait la grandeur de la tâche qu'elle poursuit, ce sont les idées d'union, de collaboration, de solidarité entre les nations qui sont à la base de sa constitution.

Ces idées d'union et de collaboration sont particulièrement essentielles lorsqu'il s'agit d'une industrie qui comme celle des combustibles est soumise à des fluctuations économiques dont l'incidence sur la vie des pays est si importante.

Plus les civilisations qui traduisent le résultat de l'évoloution des peuples au cours de leur histoire sont marquées de différences profondes, plus diffère leur manière d'envisager les problèmes nationaux et sociaux et plus les contacts sont nécessaires pour rapprocher les points de vue. Il faut se réunir pour se connaître, il faut se connaître pour se comprendre, il faut se comprendre pour s'entendre.

La Conférence mondiale de l'énergie a conquis sa place au premier rang des organisations internationales qui dans les domaines technique et économique secondent puissamment l'effort que poursuivent les gouvernements dans le domaine politique.

La contribution que la Conférence mondiale de l'énergie apporte à l'entente entre les peuples est peut-être le plus beau titre dont elle peut se glorifier.

C'est pour nous une raison de témoigner aujourd'hui notre gratitude au Comité national anglais dont nous avons à nouveau à apprécier la large hospitalité.

Je vous demande, Messieurs, de lever vos verres à la santé de nos hôtes.

Dr. E. Tissot (Switzerland) first of all thanked Sir David Milne-Watson for what he had said on behalf of Switzerland and himself. If the Basle Sectional Meeting was a success, it was due to general goodwill; and as Great Britain, of all the participants, assisted so greatly by the presentation of interesting papers and in taking part in the discussions, it followed that the Swiss people were happy and proud to receive the British delegates, and to do everything possible to make their stay in Switzerland as agreeable as possible. It was now his turn to thank the organisers of the Fuel Conference for the excellent arrangements that had been made and the splendid way in which the delegates had been received. In these circumstances the Conference could not fail to be a full success. The large number of papers presented proved the great interest the world took in this Conference and fully justified the support that had been given to the proposal to hold a world Fuel Conference. It was due to the efforts of the International Executive Council of the World Power Conference that these Sectional Conferences were proving such

outstanding successes because the policy of treating matters of general interest and organising Conferences in different countries was securing for the World Power Conference true friends from all parts of the world.

The first Sectional Meeting held at Basle in 1926 was a great success, and the present second Sectional Meeting proved once more its necessity and utility. The Basle Conference discussed the utilisation of water power in its various aspects and the present Conference completed the work in a most natural way by considering the use of fuel for power production. The progress made in the development of both sources of power had been so great and rapid in these few years that it was difficult to follow it, and it was only by Conferences such as these that a general bird's eye view of the progress made and still to be made could be obtained.

The International Executive Council had decided to prepare statistics on the power resources of the world on a comparable basis and to place them at the general disposal of the various countries of the world. Switzerland had been asked to prepare the statistics in connection with water power and had started to work already. The speaker hoped that the Sectional Meeting of London would provide the data required to enable rapid progress to be made in making the inventory of fuel resources in the world, in order that the world knows where we are, and in how many years we may have to die for want of heat as a consequence of the continuous consumption of the material generating heat.

It was true that besides water power there was still available energy from the sun and the tides, and also from the wind, and perhaps the time would come when it would be possible to store these energies economically and so replace bit by bit the energy spent by the use of fuel. The day might come when the Council would organise a Sectional Meeting for the discussion of the storage and rational use of these forms of power. As a matter of fact France and Denmark were preparing statistics on these sources of power which might yet prove to be of prime interest, and it might then be possible to replace the missing fuel power which had been exhausted and so enable life on the world to continue by the rational use of these other sources of energy.

Mr. F. V. Hansen (Sweden), in the final reply to the toast, expressed the sincere thanks of the Swedish delegation to Sir David Milne-Watson for the manner in which he had welcomed the guests. The Swedes, he said, even from old times had been in close connection with the inhabitants of England. A thousand years ago their ancestors, the Vikings, came over to this country in their

tiny craft, sword in hand, to fetch—he was afraid in a rather rough and ready manner—cargoes of English products and other much desired treasures. In present days, the Swedes still demanded the good British products, but in a more civilised way, prepared to pay for them in wares such as wood, paper pulp and perhaps Swedish matches.

Among British products, the inhabitants of Sweden specially needed coal because, in spite of Sweden's abundance of water power and its extensive utilisation, the consumption of coal was not diminishing, because many industries needed heat which was rather expensive when produced by electrical energy. Their railways, which were yet only partly electrified, also needed great quantities of coal, as did the gas works in the larger cities. Sweden had no coal seams of any importance, nor could it boast of any resources of liquid fuel, and even though their homes and streets were almost universally lighted by electrical energy obtained from the hydro-electric schemes, large quantities of liquid fuel were required by motor cars and tractors and the Swedish merchant ships which were adapting oil engines instead of steam to an increasing extent. All that fuel had to be imported and it was, therefore, highly important to work towards increased fuel economy. For this reason it was with great expectations that they came to this Conference which was to discuss so many important questions of this nature.

They were all happy to meet so many eminent specialists and to learn from their great experience. Particularly happy were they to revive old and make new acquaintances among colleagues in Great Britain because the Swedes felt very strong sympathies for the British nation which created the word "gentleman" and showed how to live up to it. They were confident that the Conference would be of lasting value to all countries of the world in regard to the fuel problems and also that it would further the friendly relations between the peoples and thereby add to the prosperity of mankind.

Col. R. K. Morcom, C.B.E. (Great Britain), proposed the final toast of the evening: "The Chairman." It was briefly acknowledged by the Marquess of Reading.

RECEPTION BY HIS BRITANNIC MAJESTY'S GOVERNMENT

On Tuesday, September 25, 1928, a reception to delegates and foreign visitors to the Fuel Conference, and others, was given by His Majesty's Government at Lancaster House. The Right Hon. Sir Philip Cunliffe-Lister, K.B.E., M.C., M.P., and Lady Cunliffe-Lister received the guests. The company was entertained with a musical programme.

As is well known, Lancaster House is the home of the London Museum, and not only the foreign visitors, but many British guests were glad to avail themselves of this opportunity for inspecting the numerous interesting exhibits.

RECEPTION TO DELEGATES AND MEMBERS OF THE FUEL CONFERENCE BY THE LADY MELCHETT AND MR. & MRS. ROBERT MOND AT HOTEL CECIL

On the evening of Friday, September 28, a reception was given by the Lady Melchett and Mr. and Mrs. Robert Mond. (Lord Melchett was unavoidably absent.) A concert was followed by dancing.

OFFICIAL VISITS

Thursday, September 27.

Port of London (by courtesy of the Port of London Authority).

Rothampstead Experimental Station, Harpenden (by courtesy of the Director, Sir John Russell, D.Sc., F.R.S.).

Tuesday, October 2.

Gas Light and Coke Company (by courtesy of the Governors and Directors of the Company).

County of London Electric Supply Co. Ltd. (by courtesy of the Chairman and Directors of the Company).

Thursday, October 4.

Fuel Research Station, East Greenwich (by courtesy of the Department of Scientific and Industrial Research).

National Physical Laboratory, Teddington (by courtesy of the Director).

Anglo-Persian Oil Co.'s Laboratories, Sunbury-on-Thames (by courtesy of the Chairman and Directors of the Anglo-Persian Oil Co., Ltd.).

In addition to these Official Visits, members of the Fuel Conference, and especially foreign visitors, were able to avail themselves of several unofficial invitations extended to them during the actual course of the Conference.

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WORLD POWER CONFERENCE

OBJECTS

They resolve that the Objects, as set forth in the Memorandum of July, 1924, should be adopted as the permanent Objects of the World Power Conference. They are as follows:—

The purpose of the World Power Conference is to consider how the industrial and scientific sources of power may be adjusted nationally and internationally:

By considering the potential resources of each country in hydro-electric power, oil, and minerals.

By comparing experiences in the development of scientific agriculture, irrigation, and transportation by land, air, and water.

By conferences of civil, electrical, mechanical, marine, and mining Engineers, Technical Experts, and authorities on Scientific and Industrial Research.

By consultations of the Consumers of Power and the Manufacturers of the Instruments of Production.

By Conferences on Technical Education to review the educational methods in different countries, and to consider means by which the existing facilities may be improved.

By discussions on the financial and economic aspects of industry, nationally and internationally.

By conferences on the possibility of establishing a permanent World Bureau for the collection of data, the preparation of Inventories of the World's Resources, and the exchange of industrial and scientific information through appointed representatives in the various countries.

WORLD POWER CONFERENCE

President
THE RT. HON. THE EARL OF DERBY, K.G.

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* *Not prepared in time for presentation at the Fuel Conference*

PROGRESS IN THE DEVELOPMENT OF COMBUSTION OF VICTORIAN BROWN COAL

AUSTRALIAN NATIONAL COMMITTEE, WORLD POWER CONFERENCE

STATE ELECTRICITY COMMISSION OF VICTORIA

Paper No. A2

CONTENTS

THE LATROBE VALLEY—FIRING OF BROWN COAL—PRE-DRYING LIGNITE—DIFFICULTIES ATTENDING PRE-DRYING—DRYING COAL IN COMBUSTION CHAMBER—COMBUSTION ON STEP GRATES—DRYING SHAFT—ARRANGEMENT OF BOILER PLANT—CLASSIFICATION OF DRYERS

ZUSAMMENFASSUNG

The potential wealth of the brown coalfields has proved an elusive mirage for many small organisations promoted for their development. As far back as 1873 the Lal Lal Brown Coal Co. unsuccessfully sought a market for brown coal from the Lal Lal brown coal area (Fig. 1), while the exploitation of the Morwell area was started in 1889 by a company which commenced operations on the banks of the Latrobe River upon a site at present occupied by the Morwell Opencut of the Electricity Commission. The company promoted to develop the Morwell area erected a small briquette plant in 1894, but after a brief period of activity, operations were suspended until 1916, when the old workings were reopened by the Mines Department of Victoria. This department controlled the operations for about five years, then they were taken over by the Electricity Commission, under whose supervision they have been actively worked up to the present time. It is, however, intended to reduce operations on the Morwell Cut in the near future, almost to the point of closing down; thereafter coal will only be taken out for special purposes. The

reason for this is that the Morwell Cut is limited in extent, and the winning of the coal becomes more costly as it becomes reduced, whereas the coal available from the New Yallourn Opencut, situated about half a mile distant, is comparatively limitless, and here operations have now developed beyond the expensive opening-up stage, so that this coal is now on an equal economic basis with coal from the Morwell Cut, and likely to give more economic results in the future.

The large area of brown coal known as the Altona area (Fig. 1) is near to Melbourne, but owing to the depth of overburden, deep mining is necessary for its development, with the result that up to the present very little exploitation has taken place.

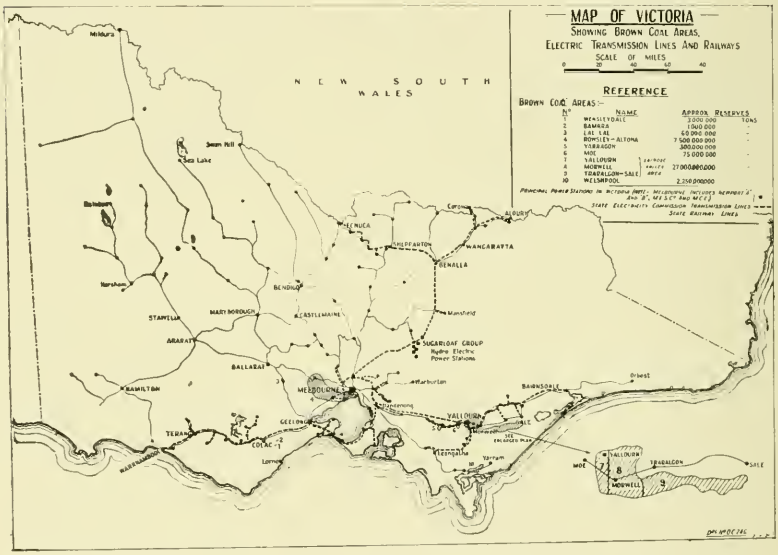

Fig. 1. Map showing the location and extent of the Victorian brown coalfields.

At the present time a little coal is being mined at Lal Lal and Wensleydale, but operations are on a very small scale.

The Latrobe Valley

Deposits of brown coal occur in Tertiary beds, principally composed of fresh-water sands, clays, and gravels, but owing to the faulting and tilting to which the area has been subjected, it is only possible to ascertain the exact occurrence of coal in this deposit by

intensive boring. Some of the bores put down in the Latrobe Valley have proved that brown coal seams exist of unprecedented thickness, for example, bore No. 1 in the parish of Maryvale, close to Morwell township, showed coal beds aggregating 770 ft. thickness in a bore 1,019 ft. deep; bore No. 2 in the parish of Maryvale, about four miles north-easterly from bore No. 1, showed 484 ft. of coal in a bore 1,338 ft. deep, while bore No. 2, in the parish of Traralgon, two miles south-easterly from the second bore mentioned above, showed 480 ft. of coal in a bore 1,110 ft. deep. It is interesting to note that not one of the three bores mentioned above had passed beyond the coal measures when boring ceased, hence it can reasonably be assumed that more coal exists below the bottom of the bore holes.

The brown coals from the Morwell Opencut and the New Yallourn Opencut of the State Electricity Commission are very different in physical characteristics, inasmuch as the Morwell coal has a moisture content of less than 50 per cent., while the Yallourn coal is usually 64 per cent.; moreover, the Morwell coal is of a hard nature, while the Yallourn coal is an extremely friable earthy-looking brown coal, similar in appearance to some of the soft middle German brown coals. Typical ultimate analyses on the dry coal basis of the brown coals from Victoria, South Australia and Germany are given in Table I. Analyses made on

TABLE I. TABULATION OF ULTIMATE ANALYSES OF VARIOUS BROWN COALS

All Figures are Percentages

	Victorian Brown Coals				South Australian Brown Coals		German Brown Coals		
	Morwell (old open-cut)	Yallourn (new open-cut)	Altona	Lal Lal	Moorlands	Clinton	Rhineland	Middle Germany	Neider-lausitz
Carbon ..	65·62	64·87	61·45	63·05	55·95	59·12	65·27	61·2	62·5
Hydrogen ..	4·62	4·43	4·44	5·00	4·25	4·10	4·82	5·6	5·2
Oxygen ..	24·67	27·84	20·76	27·01	21·85	18·09)	25·63	19·3	23·2
Nitrogen ..	0·60	0·54	0·69	0·75	0·40	0·63)			
Sulphur ..	0·27	0·24	2·31	0·44	4·30	3·35	0·22	2·4	0·8
Ash	4·22	2·08	10·35	3·75	13·25	14·71	4·06	11·5	8·3
	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00

samples of the Yallourn and Morwell brown coals taken daily during 1927 as the coal was delivered to the Yallourn power station gave the following figures (Table II).

TABLE II.

	Morwell coal		Yallourn coal	
	As fired	Dry	As fired	Dry
Moisture ... per cent.	48·5	—	63·4	—
Volatile matter ... ,,	27·3	53·0	19·0	52·1
Fixed carbon ... ,,	22·0	42·8	16·8	45·8
Ash ... ... ,,	2·2	4·2	0·8	2·1
Gross calorific value—				
B.Th.U. per lb. ...	5,736	11,140	3,979	10,870
Net calorific value—				
B.Th.U. per lb. ...	4,998	—	3,156	—
Carbon ... ... per cent.	33·79	65·62	23·74	64·87
Hydrogen ... ,,	2·38	4·62	1·62	4·43
Oxygen ... ... ,,	12·71	24·67	10 19	27·84
Nitrogen ... ,,	0·31	0·60	0·20	0·54
Sulphur ... ... ,,	0·14	0·27	0·09	0·24
Ash ... ... ,,	2·17	4·22	0·[illegible]	2·08
Moisture ... ... ,,	48·50	—	63·40	—

The limiting values of calorific power, ash, hydrogen and moisture content obtained during the routine testing in 1927, were as follow :—

TABLE III.

	Morwell coal	Yallourn coal
Calorific value—		
B.Th.U. per lb. gross dry—		
Maximum value	11,260	10,925
Minimum value	10,790	10,810
Ash content—dry basis—		
Maximum value	5·2	2·4
Minimum value	3·7	1·9
Hydrogen content—dry basis—		
Maximum value	4·72	4·55
Minimum value	4·50	4·25
Moisture content—		
Maximum value	51·8	65·4
Minimum value	40·0	62·7

Firing of Brown Coal

In designing boiler plants intended to utilise brown coal in the raw state, many difficulties are experienced, due principally to the moisture present in the raw fuel and the relatively low heat value of the combustible in the coal. The moisture in the fuel results in an increase of the stack losses with a corresponding

decrease in the thermal efficiency, while the aggregate effect of the high moisture and low heat value of the combustible is that the grate area must be made correspondingly larger.

In order to obtain practical information relating to the combustion of the Morwell brown coal containing under 50 per cent. moisture, a series of tests was carried out in 1909 at the Newport railway workshops on a Babcock & Wilcox boiler fitted with a "Cotton" furnace, the latter being simply a rectangular closed shaft without a grate. Although these tests were satisfactory from the point of view of efficiency, it was evident that the furnace construction was not one applicable to large units.

A series of tests was commenced in 1917 at the Melbourne City Council's power station, with the result that the furnace and grate arrangement shown in Fig. 2 was evolved. The arrangement

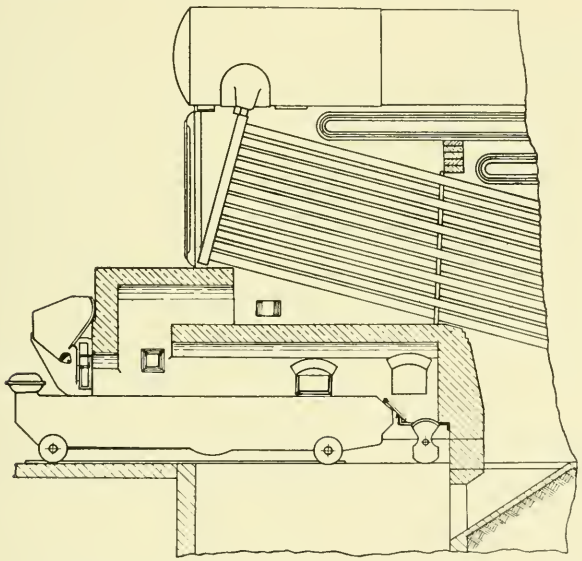

Fig. 2. Furnace arrangement for burning Morwell brown coal at the Melbourne City Council power station.

shown is a Babcock & Wilcox boiler with a heating surface of 4,780 sq. ft., which was used for the majority of the tests. The unit was equipped with a Babcock chain grate of 96 sq. ft. area arranged for use with air pressure under the grate. It will be noticed that the return arch setting compels the major portion of the hot gases to pass back over the wet coal coming on to the

grate, as experiments proved that an arch arranged to cover the front sections of the grate only would not ignite a fuel containing 45 to 50 per cent. moisture.

The results of the above trials, which were confirmed by tests made on a boiler plant erected for a temporary source of electrical energy for the development of the Yallourn undertaking, were considered conclusive enough to be used as a guide in designing the grate and furnace equipment for the Yallourn power station. The type of grate adopted for the power station was the Underfeed Stoker Co.'s class "A" balanced draft stoker, arranged in the manner shown in Fig. 3, from which it will be seen that the

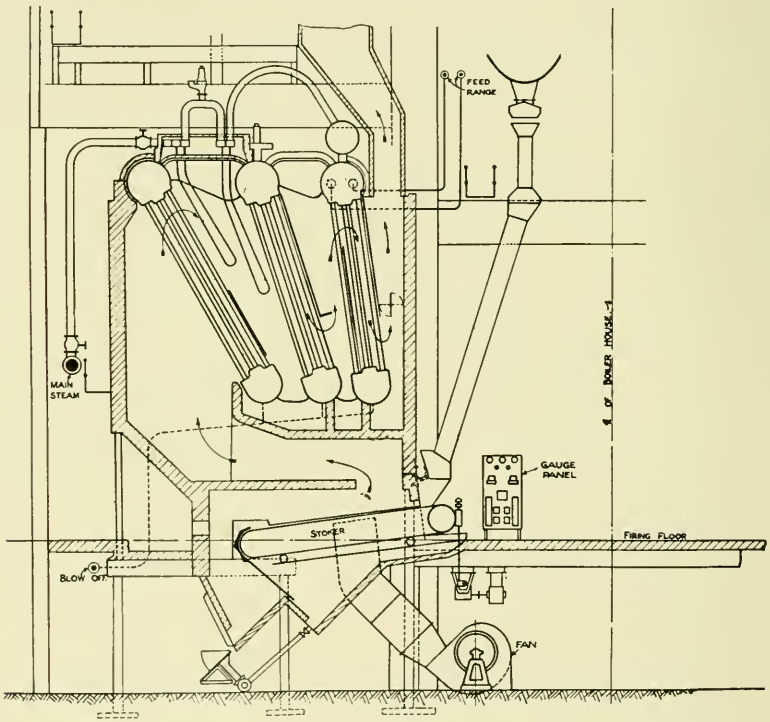

Fig. 3. Arrangement of a boiler unit as originally installed at Yallourn.

return arch combustion chamber was adopted, but with an increased length of flame travel from the grate to the boiler heating surface. The boiler house consists of twelve boilers each of 14,425 sq. ft. heating surface, equipped with integral superheaters of 2,727 sq. ft. heating surface, and fired by three grates each

122 sq. ft. in area. Forced and induced draft fans are fitted, the latter discharging into six self-supporting steel chimneys 13 ft. internal diameter and 170 ft. high from the firing floor to the top of the stack. Each boiler unit is rated to evaporate 70,000 lb. of water per hour from feed at 160°F., into steam at a pressure of 260 lb. gauge and a temperature of 650°F.

Table IV gives a summary of three acceptance tests made on one of the boiler units of the power station when burning the Morwell brown coal for which the plant was designed, and show that with a creditable efficiency the grates are capable of burning over 60 lb. of raw coal per square foot per hour, corresponding to a heat liberation of 314,000 B.Th.U. per square foot of grate per hour.

TABLE IV.

ACCEPTANCE TESTS ON No. 4 BOILER—YALLOURN, 1925

Type of Boiler, John Thompson Water Tube.
Maker's Rating, 70,000 lb. steam per hour from feed at 160°Fah.

Boiler heating surface ... ... sq. ft.	14,425	14,425	14,425
Superheater heating surface ... sq. ft.	2,885	2,320	2,320
Grate area (three grates) ... sq. ft.	368	368	368
Date of test	7/4/25	27/5/25	1/7/25
Duration ... ... Hours	8	8	8·266
Percentage of Maker's normal rating per cent.	110	98·4	105·5
Percentage of A.S.M.E. normal rating ,,	200	172·4	184·6
Coal—Run-of-mine Old Open Cut Brown			
Fines in coal (under ¼″) ... per cent.	13·9	14·7	11·8
Oversize in coal (over 2″) ... ,,	9·2	10·7	7·1
Moisture ... ... ,,	46·3	47·9	48·0
Volatile matter ... ... ,,	27·9	27·51	28·1
Fixed carbon ... ... ,,	23·0	22·53	22·5
Ash ... ... ,,	2·8	2·07	1·4
Hydrogen in dry coal ... ,,	4·00	4·47	4·54
Dry calorific value (gross) B.Th.U., per lb.	11,201	11,242	11,496
Net calorific value as fired ,,	5,322	5,131	5,247
Total weight fired in test ... ... lb.	192,072	183,080	183,170
Consumption per hour ... ... lb.	24,009	22,885	22,159
Consumption per sq. ft. grate per hour—			
Left grate ... ... lb.	67·4	57·3	61·81
Middle grate ... ... lb.	65·2	55·3	54·09
Right grate ... ... lb.	63·2	60·1	65·38
Water—Total evaporation ... ... lb.	617,960	551,472	610,700
Evaporation per hour ... ... lb.	77,245	68,934	73,881
Evaporation per hour per sq. ft. B.H. surface ... ... lb.	5·35	4·78	5·12
Evaporation per lb. coal (actual) ... lb.	3·22	3·01	3·33
Feed temperature ... ... °Fah.	176·1	169·0	159·9

TABLE IV.—*continued.*

ACCEPTANCE TESTS ON No. 4 BOILER—YALLOURN, 1925

Steam—Average pressure (gauge) ... lb.	254·2	254·5	255·3
Average steam temperature... °Fah.	750·5	677·6	649·4
Superheat ... ... °Fah.	343·0	270·0	241·5
Heat to generate 1 lb. steam from feed B.Th.U.	1,243·4	1214·0	1209·0
Air—Boiler-room temperature °Fah.	64·6	57·5	54·1
Air pressure under grate—			
Left grate ... ... in.	0·20	0·22	0·23
Middle grate ... ... in.	0·21	0·09	0·12
Right grate ... ... in.	0·22	0·14	0·22
Draught at back of grate—			
Left grate ... ... in.	–0·07	–0·01	–0·01
Middle grate ... ... in.	–0·10	–0·09	–0·05
Right grate ... ... in.	–0·05	–0·08	–0·08
Draught leaving furnace		–0·01	–0·03
Draught at boiler exit (before damper) in.		–0·37	–0·40
Ash—Weight of ash (dry) ... ... lb.	723	1,304	293
Weight of spillage (dry) ... ... lb.	1,219	2,116	1,239
Carbon in dry ash ... ... per cent.	62·7	43·3	29·7
Carbon in dry spillage ... ,,	46·5	24·0	21·1
Flue Gas—Percentage of CO_2... ...	14·6	15·4	16·6
Temperature of furnace ... °Fah.	2,433	2,347	2,484
Temperature of boiler exit gas °Fah.	606	607	597
Economic Results—Water evaporated per lb. coal fired and at 212°Fah. ... lb.	4·12	3·77	4·15
Net efficiency boiler, grate superheater per cent.	75·17	71·27	76·82
Net efficiency boiler and superheater ,,	—	72·57	77·27

Under normal operation it was usual to operate at higher ratings and it has been found possible, under ordinary operating conditions, to burn up to 83.5 lb. of coal per square foot of grate per hour, corresponding to a liberation of 417,500 B.Th.U. per square foot of grate per hour, when burning the Morwell coal with under 50 per cent. moisture.

Pre-drying Lignite

The combustion of the Yallourn brown coal with its moisture content of 64 per cent., however, has presented infinitely greater difficulties than the utilisation of the Morwell coal. When it became manifest that the Yallourn coal from the new opencut, which was to be the source of fuel for the power station, possessed this high percentage of moisture, it was at once realised that the chain grate and combustion chamber design, which had

proved successful for the Morwell coal, would not be so completely satisfactory when burning the Yallourn coal, inasmuch as the grate area would be insufficient, while there was an impression that the chain grate construction would be unsuitable for drying and burning a coal with a moisture content of over 50 per cent. This subsequently proved to be the case. It was natural that the idea should be formed of designing some type of apparatus which would dry the coal before it passed on to the chain grates; such a system offered marked advantages, inasmuch as the deficiency in the grate area could be thereby overcome with a concomitant increase in combustion efficiency.

The first trials in this direction were made on a boiler at the Yallourn temporary power plant previously mentioned, with a view to testing the advantages of pre-drying with coal from either source.

The first scheme adopted was to use the hot flue gases at the boiler exit for drying the fuel, as shown in Fig. 4. In this dryer

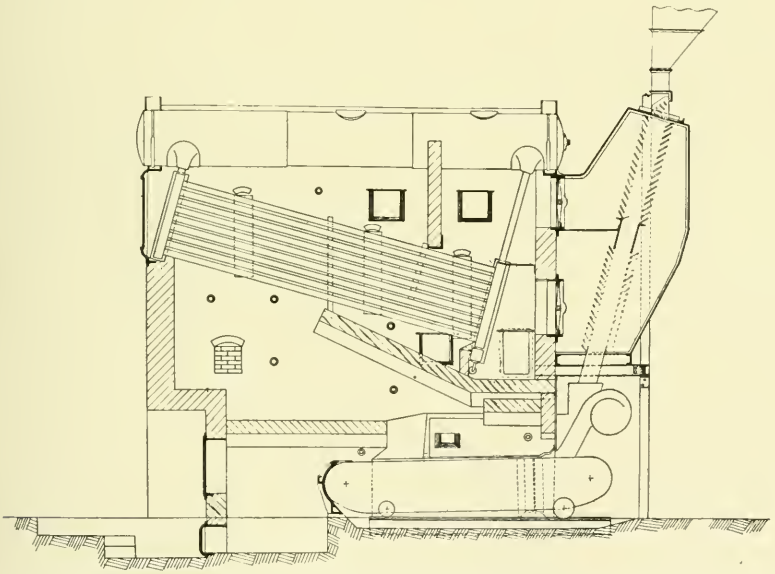

Fig. 4. Arrangement of boiler and flue gas dryer unit as installed in the Yallourn temporary power plant.

the coal was passed through a chute having two louvred walls $6\frac{1}{2}$ in. apart, while arrangements were made to pass the hot flue gases from the boiler exit, first through the top half and then

through the lower half of the coal column in the chute. The experimental unit was a Babcock & Wilcox unit with 2,436 sq. ft. heating surface, equipped with compartment type travelling grate stoker and having an area of 85.7 sq. ft. It was found subsequently from practical trials that the best results were obtained when the flue gases were distributed over the whole face of the louvred chute, so that they only made one traverse of the column of coal. A typical test on the experimental unit when being used as a single pass dryer using Yallourn brown coal, screened so that all the coal passing through the unit was between the limits of 2 in. and $\frac{3}{8}$ in., gave the following results :—

Moisture in coal entering dryer=64.7 per cent.
Moisture in coal leaving dryer=57.8 per cent.
Net calorific value coal entering dryer=2,973 B.Th.U. per lb.
Net calorific value coal leaving dryer=3,760 B.Th.U. per lb.
Coal entering dryer per sq. ft. of chain grate area per hour=57.6 lb.

A design of dryer for the use of screened coal and based on the original experimental dryer was then evolved for the boilers (Fig. 5) of the main power station. The original scheme with the 50 per cent. moisture coal contemplated the use of screened coal at the power station conjointly with the utilisation of the residual fine coal in the briquette factory, and there appeared every justification to adhere to this proposal for the higher moisture coal. Tests on these dryer units indicated that when Yallourn brown coal, screened to a maximum size of $1\frac{1}{2}$ in., and when only a very small percentage of coal below $\frac{1}{4}$ in. in size was being used, an average furnace temperature of 2,200°F. was obtained with 13.2 per cent. of CO_2 in the flue gases. Samples of coal leaving the dryer, taken when the unit was operating at approximately normal rating of 70,000 lb. per hour, showed that the coal had 65.4 per cent. moisture entering the dryer and 55.2 per cent. leaving the dryer. This was very satisfactory, the output of the boiler being 30 per cent. higher than its performance when operating on the 64 per cent. moisture content Yallourn coal of the same texture but with the plant as originally installed for 50 per cent. moisture coal.

For a time the use of screened coal of this texture was employed at the power station, but soon the difficulties accompanying the screening of coal having the Yallourn characteristics became so serious as to make it clear that a change of method was necessary.

The ordinary types of screens employed became continually choked, owing to the excessive plasticity of the coal, in spite of the use of various ingenious scraping and cleaning devices. The very process of screening due to the coal's earthy structure only created still more fine coal, consequently, the rejected residue of fine coal which was to be disposed of in the briquetting plant was so large in quantity that the briquetting factory could not use it at all; moreover, the briquetting factory boiler staff were experiencing the same difficulties as were met with at the power station in maintaining steam output, when a large percentage of fine coal was used.

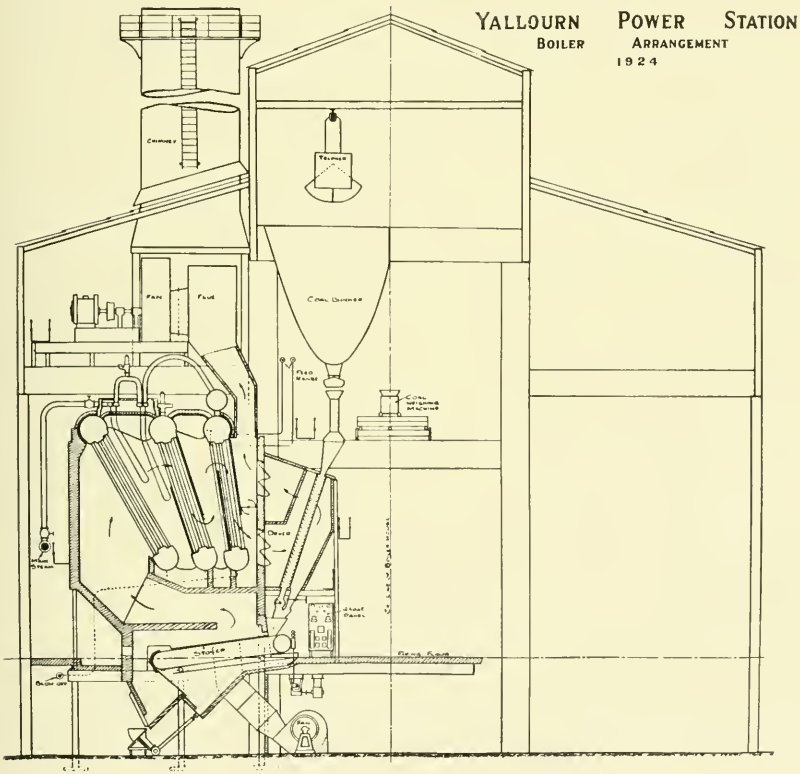

Fig. 5. Arrangement of boiler and flue gas dryer unit as installed in the Yallourn power station.

The natural result was an endeavour to use coal at the power station having a larger percentage of fines and a wider range of size in the texture.

When such a grade of coal was tried in the dryers it was found impossible to maintain the same outputs as with the better screened coal, for several reasons :—

The regular flow of coal down the louvred chute was frequently interrupted by bridging across the chute, or partial holding-up due to the earthy plasticity of the coal, followed by a run or slide which packed the chute so tightly, the intermittency being very frequent, that the available induced draught fan capacity was not sufficient to draw the gases through the increased resistance of the column of coal.

In order to bring the output up to anything approaching within 15 per cent. of the output obtainable with the coal for which it was designed, it was necessary to by-pass such a large proportion of the gases that the measurable drying effect was reduced to what appeared to be an insignificant quantity. Nevertheless, it was conclusively proved that the dryer was performing a very useful function, as by operating in this way the boiler output was about 12 per cent. higher than when operating without the dryer in operation. It was presumed that this improvement arose from the coal in its passage through the hot gases having been brought to a state in which it was more readily ignitible, firstly by the coal mass having absorbed sensible heat, and secondly by small particles, and the surfaces of larger pieces having dried off to the degree of being ready to ignite, and while burning so to hasten the drying of the bulk of the coal after entering the furnace.

The next step was an endeavour to reduce the draught drop through the coal column, so as to draw a larger proportion of the gases through and thus to bring more of the coal pieces into intimate contact with the heating medium. The easiest way to obtain this end without radical alterations and with the same fans, which could not readily be replaced, was to make the louvred chute narrower. This was done on one of the boilers, reducing the coal thickness from 6½ in. to 4½ in.

It was then found that the packing in the chutes became more local, due to the larger lumps assisting the bridging by catching on the ridges formed by the louvre blades. The clearing of the obstructions became such a serious, tedious, and dangerous operating feature that continuance of operation was manifestly impracticable. With this arrangement there was no doubt that a larger proportion of the gases passed through the dryer, but as the fine dust was dried off it was carried out of the chute by the high

velocity of gases and deposited in the recesses of the dryer at such a rate as to choke the passages.

The local holding-up of the coal was responsible for uneven concentration of gas penetration, tending to want of uniformity in drying and consequent irregularity in output of the boiler. No doubt more drying took place, but the practical difficulties nullified its useful effect.

About this period four out of the ten boilers then in operation had been fitted with dryers, and one of these had been made for double passage of the gases instead of single pass, and although the draught loss through the dryer was somewhat more than with the single pass dryers, it has always been claimed by the operating staff that with a good texture of coal this unit gave a better performance than the others.

Difficulties Attending Pre-Drying

At this stage it had been demonstrated that the principle of direct drying by waste flue gases, though fully successful from the point of view of performance and with the correct texture of coal available, could only be applied successfully under the conditions to be met at Yallourn by overcoming certain fundamental difficulties, namely:—

1. Excessive draught loss.
2. Irregular bridging of coal and resulting want of uniformity of coal and gas flow.
3. The early drying of the fine dust and its excessive escape from the coal chute.

With a view to equipping the remainder of the boilers with an improved type of dryer, attention was then given to the possibilities of drying by a free intermixing of the gases and coal particles while the latter were allowed to fall freely.

The design of an appliance which was evolved and tested on an experimental scale is shown in Fig. 6.

The hot flue gases entered the dryer at the bottom and were compelled by means of baffle plates to traverse the coal as it was falling down the chute.

The tests on this appliance showed that with the space available on the Yallourn plant this system:—

1. Would not attain the required reduction in draught loss and at the same time give the requisite improvement in performance;

2. Resulted in a considerable loss of fine semi-dried coal dust, probably more than in the louvre type of dryer;
3. Was considered to be too complicated from the operating point of view, because of the moving parts.

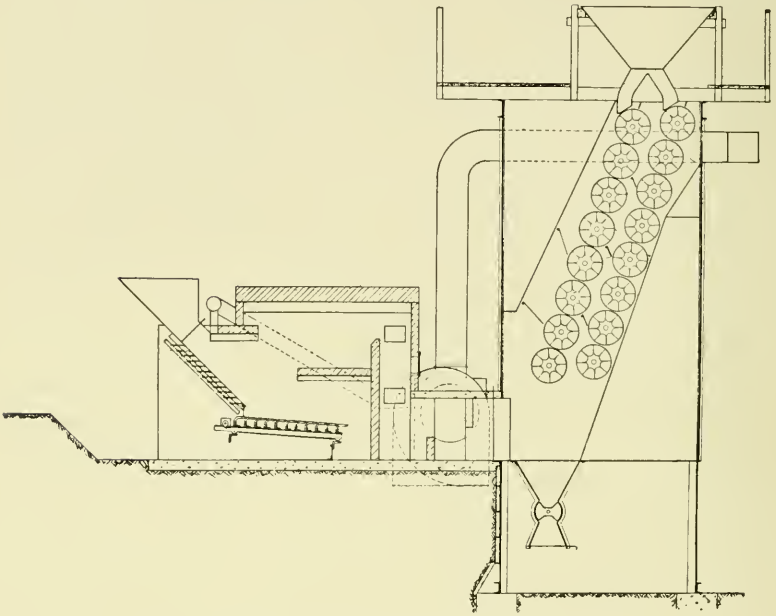

Fig. 6. Sketch of experimental flue gas dryer.

About the time these conclusions had been reached, the exigencies of the demand for further output from the power station called for steps to be taken to attain quicker results than were promised by the pursuit of further problematical experimental research.

The possibility had been kept in view of increasing the original grate area by means of a supplementary grate, and a movement was made towards developing this proposal. In the meantime, it was felt that before abandoning the dryers on the four boilers so fitted, a further modification should be made on one of them to ascertain the effect of passing the stream of coal through an atmosphere of waste flue gas without the induction of the gases through the interstices of the coal column. Baffles were arranged to give the gases a longer and more sinuous flow around the coal chute, which was, in this case, widened out to 12 in.

The results in this case, as in the other efforts, tended to show the inadequacy of the small space available. The widening of the chute had been decided upon on account of the tendency for the coal texture supplied to the power station to have an increasing range of size, and naturally this prejudiced the transfer of heat to the interior body of the coal, while again the limitations of draught and the restricted available headroom precluded the gases and coal stream remaining sufficiently long in contact with one another to give the desired degree of increased output from the boiler.

Although the Commission's research on flue gas dryers has been prolonged owing to the necessity for meeting the requirements of commercial service while making experiments, it must not be concluded that it has been exhaustive, and some regret is felt that conditions will not permit of further investigations into a system involving the principle of expelling moisture from the coal before attempting to pass it into the furnace.

One advantage of the dryers installed at Yallourn power station which has always been appreciated by the operating staff was the means they provided for the preparatory drying of a charge of coal in the chutes, holding about 8 tons, in readiness for the sudden rise on peak loads. The effect of this hot semi-dried coal rapidly passed on to the grates had a very marked effect upon the station's ability to weather the peak load rise.

Experience having demonstrated that the successful application of low-temperature flue gases to coal drying would require a good deal more space than was available, and also would involve considerable developmental work, it was decided to dismantle the dryers one by one as other substitutes become available. Only one dryer now remains.

Drying Coal in Combustion Chamber

In order to overcome the inherent difficulties incidental to using the low-temperature flue gases, the next modification towards bringing up the capacity of the boiler plant on the high-moisture coal aimed at drying the coal after it had entered the combustion chamber, thereby gaining the advantage of the furnace temperature; in other words, introducing the raw coal direct on to an increased grate area.

The first form of apparatus (Fig. 7) was simply an inclined grate surface supplementing the chain grate, and made up of

stepped bars exposed to radiant heat, and to a limited extent a transfer of heat by conduction from the hot gases in contact with the coal surface. The angle of the fixed grates was such that the coal flowed by gravity in a stream from the chute to the travelling chain grate. The transfer of heat to the incoming coal was not

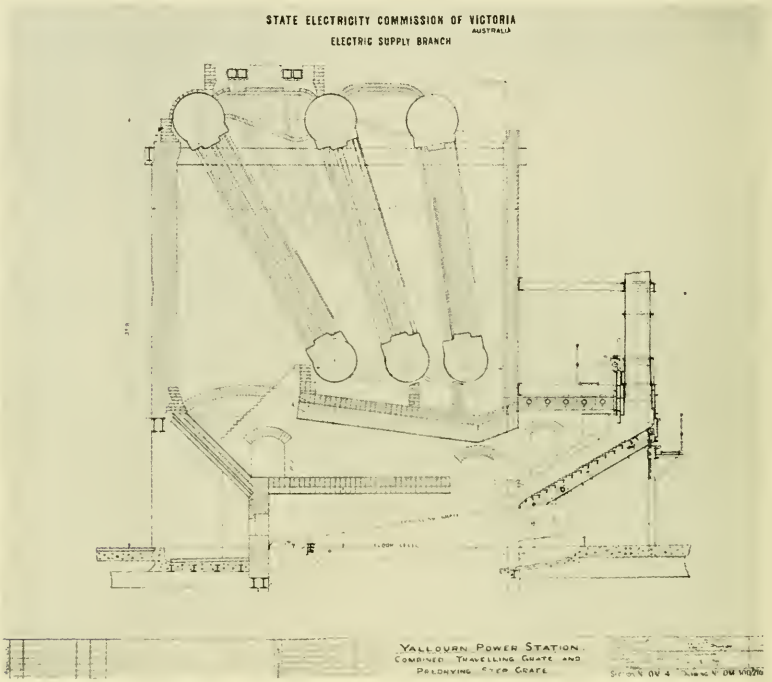

Fig. 7. Arrangement of Yallourn boiler unit equipped with inclined supplementary step grates.

sufficiently rapid to dry off and ignite the surface stream of coal before it reached the combustion zone, but it was sufficient to commence the drying process immediately the coal entered the head of the fixed step grate. In addition to this surface drying there was a degree of heating and drying taking place on the underside of the stream of coal derived from the underburning of the coal lying between the bars of the grate and sheltered from the onward movement of the coal. This action can be readily understood when it is appreciated that, unlike black coal, the Yallourn brown coal, when dry, will ignite at a temperature of approximately 370°F., provided sufficient air is present.

The auxiliary step grates have had quite an appreciable effect on the capacity of the boilers, loads of 74,040 lb. of steam per hour being obtained from the boiler units when burning Yallourn brown coal with the pieces of coal over 2½ in. in size screened out. This evaporation is equivalent to 77.6 lb. of coal consumed per square foot of total grate area per hour, corresponding to a heat liberation of 239,600 B.Th.U. per square foot of total grate area per hour.

With fixed inclined grates preceding the chain grates, difficulty was experienced when large fluctuations in the size of coal occurred, hence it was felt that a mechanical movement of the inclined grate bars would be advantageous; especially as, in addition, it would break up the fuel bed, thereby allowing access of air to the pieces of coal below the surface of the coal stream. Preliminary trials on a unit equipped with a mechanical type predrying grate, working in conjunction with a chain grate, have shown that a mechanical movement facilitated the control of the coal flow down the inclined surface, but have also demonstrated that the increase in drying incidental to the mechanical movement has not been very marked.

Up to this juncture all efforts at Yallourn power station had been directed towards increasing the capacity of the existing plant, but it now became necessary to give some thought to trying alternative methods for extensions to the power station in a second boiler house, which the increasing demands on the system would shortly require. The two most practicable systems which suggested themselves were :—

1. Pulverised dried brown coal.
2. Raw brown coal on step grates.

Of these, the latter presented fewer difficulties and uncertainties, and upon investigation promised to be more economic.

Combustion on Step Grates

It was recognised from the inception of the experimental work on the Yallourn coal, that the inclined step-grate type of unit had great possibilities where a fuel containing a moisture content greater than 50 per cent. was to be handled, hence one of the original boiler units of the main power station, which was not equipped with chain grates under the original contract, has been fitted recently with inclined mechanically moving step grates to operate with air pre-heated to a moderate degree.

In the following paragraph are given the considerations which

led up to the adoption of the particular system of firing applied to this boiler, and which will form the basis for an almost similar system proposed for the first section of the second boiler-house plant.

It is possible to divide the methods of firing raw brown coal on inclined step grates into two general divisions:—

(*a*) Fixed inclined step grates set at such an angle that the coal flows downwards due to the action of gravitational forces only.

(*b*) Mechanically moving inclined step grates, in which the coal is assisted in its passage down the grate by a horizontal reciprocating or rocking motion of the bars. This form of grate will obviously, for a coal of similar texture, have a much smaller angle of inclination to the horizontal plane than a fixed step grate.

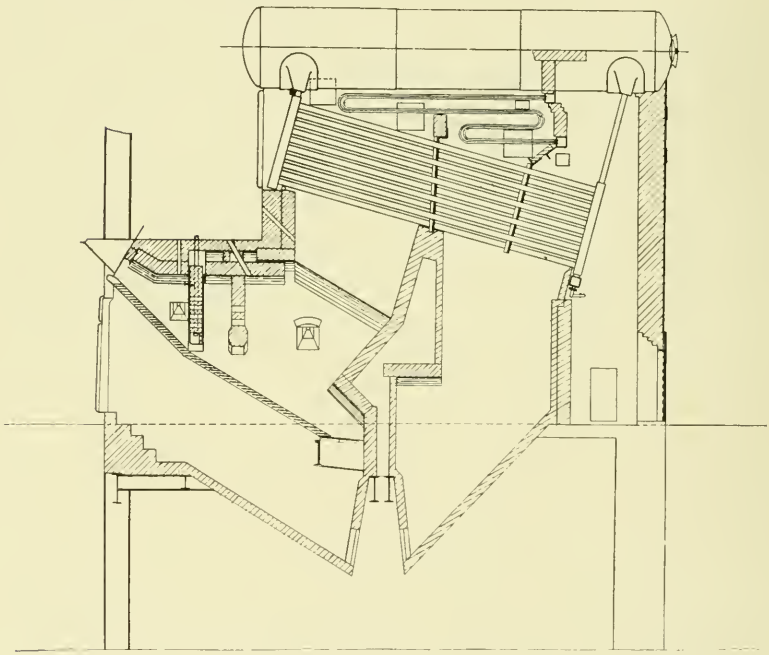

Fig. 8. Stationary inclined step grate unit installed in the Yallourn Briquetting Works.

The fixed step grates may be further subdivided into two types, the distinguishing feature lying in the furnace design. Sketches of grates belonging one to each of the subdivisions of fixed step

grates are given (*a*) in Fig. 8, showing a boiler unit installed in the original boiler house of the Yallourn Briquetting Works and (*b*) in Fig. 9, which illustrates a type of furnace considered in designing the extensions to the Yallourn Briquetting Works. It will be seen that the first type (Fig. 8), which is called the "half-gas" or "pre-gasifying" step grate, has a furnace designed so that two firebrick walls project downwards from the roof of the

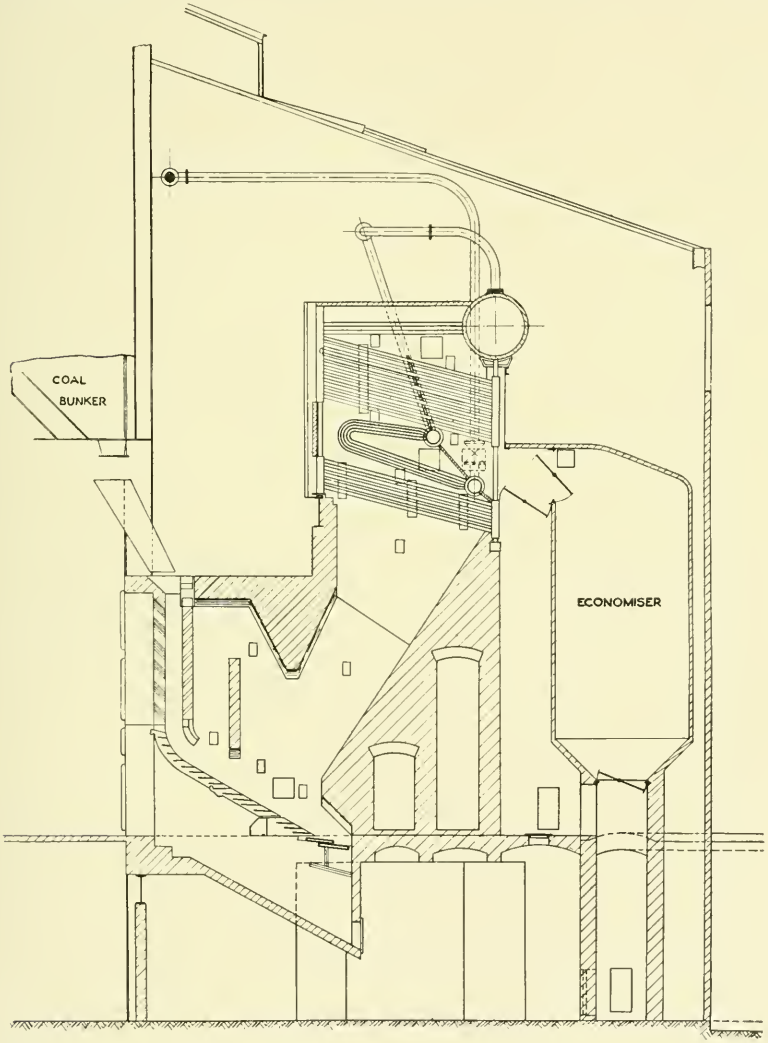

Fig. 9. Arrangement of a boiler unit with stationary step grate and coal drying shaft.

furnace to a point quite close to the fuel bed. These walls are of chequered design to permit free flow of gases, and form a drying chamber and pre-gasifying chamber. The second type of fixed grate (Fig. 9) has one large combustion chamber, in the front part of which a drying shaft and a firebrick wall are so placed that some of the gases are deflected from the main gas flow and are directed so as to take a return path and sweep the inside face of the drying shaft.

The most important point to notice about burning brown coal on inclined step grates, whether mechanically moving or fixed, is that the fundamental principle governing the burning of brown coal is fulfilled to a certain extent automatically, *viz.*, the coal in the pre-heating and drying zone is in a thick bed, while in the combustion zone it is thin. This accomplishes two important things :—

(*a*) Supplies the major portion of the air to the thin portion of the fuel bed, that is, to the active portion of the fire.

(*b*) Provides a large quantity of semi-dry coal sufficient to meet the normal fluctuations in the steam demand from a boiler unit without adjustments of fuel bed thickness and without demanding, in the case of a mechanical type of grate, such close and concurrent attention to stoker speed regulation as is demanded with the horizontal chain grate.

A very important factor in the success of a grate to burn brown coal is that the bars of the grate should be designed to encourage "under-burning" to take place to the fullest extent possible. "Under-burning" is the name given to the burning of the coal which accumulates between the bars and which does not pass along at the same speed as the coal itself. This coal, being stagnant, dries readily and ignites, thus creating a marked drying effect on the fuel bed. In the case of the older forms of fixed step grates under-burning was attended with a serious drawback, inasmuch as it increased the objectional effects of puffing out of the flame when the coal avalanched. In Germany it is customary to attribute the cause of this puffing out of flame from the grates at intervals to the pressure wave set up in the furnace, consequent on the sudden resumption of the flow of the coal after a stick-up has taken place on the grate surface.

As the puffing out is due to uneven flow of the coal, it is obvious that it will occur mainly in stations where the coal is extremely variable in texture, and especially in plants equipped with the older forms of fixed step grates, which are of necessity installed

at steep angles. With the advent of the mechanically moving grate with its smaller inclination and regulating devices, it is possible to cause the coal to flow more evenly, with the result that this trouble does not occur in plants using mechanical grates.

One of the advantages of the mechanical type step grate lies in its capacity for handling fluctuations in coal texture and the comparative ease with which increasing and decreasing loads can be met. In the case of the half-gas fixed step grate, the thick fuel bed can serve to meet small load fluctuations, but large variations cannot easily be met without manually assisting the coal and constant supervision. This is a very difficult and laborious operation with grates as long as are required on modern large boilers and where high moisture coal is used—if hot air is to be introduced under the grates, it is still more difficult to arrange for.

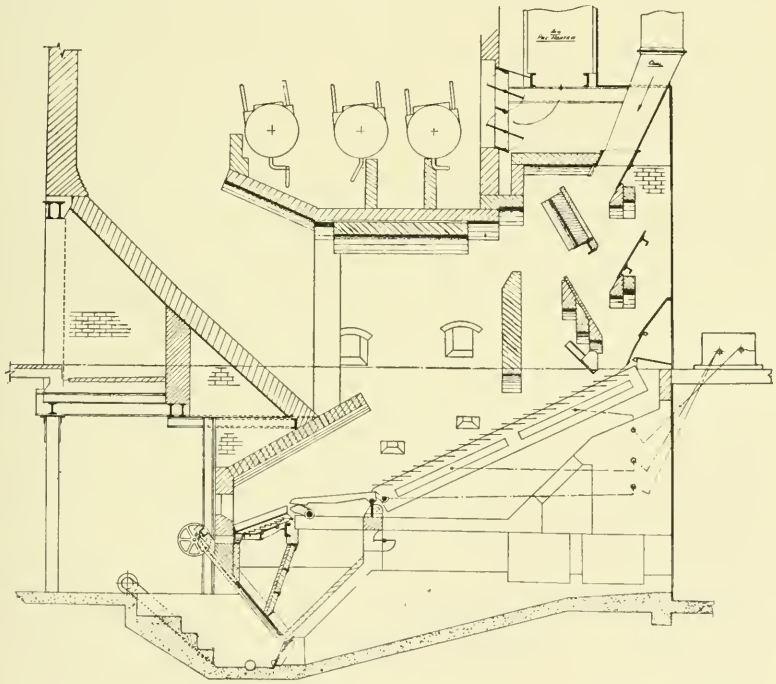

Fig. 10. Mechanically operated step grate boiler unit installed at Yallourn Power Station.

The basic design of the mechanical step grates installed under one of the boiler units at Yallourn power station (Fig. 10) makes it possible to control the coal in three different places on the grate

surface, with the result that the combustion process is capable of more accurate and efficient control than with other forms of grates. This advantage in combustion control is not obtained without certain disadvantages, as it complicates the design of the grate and, moreover, demands more skill on the part of the attendant.

Another interesting feature of the design of grate adopted is that the rear section of the grate, which is almost horizontal, permits of adjustment while the unit is in actual operation. It will be noted that a small fixed type of step grate is set so as to receive the discharge of ash and unburned coal from the horizontal moving grates. This fixed grate has a two-fold function to perform :—

(*a*) It must burn off any extra large pieces of coal which, owing to their variable drying characteristics, cannot be burned in the time interval allowed for the burning of the finer sized coal.

(*b*) To burn the fine coal particles which separate out from the gas passing out of the combustion chamber. The particles which lodge on the inclined rear wall of the furnace fall down through holes at the junction of the rear inclined arch and this furnace wall.

The small fixed step grate, therefore, acts as an automatic preventive of coal passing unburnt into the ash pit, and obviates to a large extent the amount of attention necessary when the unit is carrying fluctuating loads and when operating on a variable sized coal, such as that supplied to Yallourn power station.

It will be noted, on reference to Fig. 10, that the step grate unit, contrary to accepted Continental practice, is not equipped with a gear-operated variable fuel gate between the drying shaft and the mechanical grate, as it was felt that frequent adjustment of the fuel gate would not be necessary with a mechanical grate in which the rate of flow of the coal down the grate is principally controlled by the variable speed of the moving bars. In the case of a fixed step grate without a drying shaft and without any controllable movement of the bars, a gear-operated fuel gate is absolutely indispensable, because the grates must be set at a steep angle sufficient to cause the coal to flow by gravity under any rate of coal feed, and the best way to check the flow on light loads is to do so by lowering the fuel gate. The alternative would be to make the angle of the grate adjustable by quick operating gear,

but this would entail a cumbersome complication which is not considered practicable. In the case of mechanically-operated step grates, the position is entirely different, inasmuch as the mechanical grates are set with a smaller inclination (one well-known Continental grate manufacturer has 6° difference in slope between the mechanical and fixed designs); in fact, one of the leading advantages of the mechanical grate is that it can be set at a low enough angle to prevent the smothering of the active fuel bed at low ratings, dependence being placed on the mechanical movement to complete the inducement for the coal to flow. The normal fluctuations in demand are, therefore, met by adjusting the speed of the mechanical actuating device; provided there is a sufficient range of speed, there is apparently no need for regulation by fuel gate. This is especially the case where a mechanical grate is operated in conjunction with a drying shaft, but it must be noted that the determination of the correct size of the incoming coal opening will vary with the grate design and physical properties of the coal; hence, in the Yallourn units, although a gate capable of being raised and lowered during operation is not provided, there is a fixed weir gate which can be adjusted in height when the unit is not in service, for varying the opening available for coal flow, so that the operating mechanisms for the fuel gates can be entirely dispensed with.

Drying Shaft

Following on the success of the inclined fixed grates when applied to the chain grates, it was decided that any step grate, in order to make the most of the space available, should be equipped with some form of drying shaft situated inside the combustion chamber. A form of drying shaft (Fig. 9) used on the Continent consists of two louvred walls about 21 in. apart made of firebrick blocks set in cast-iron side frames and arranged so that a small part of the main body of furnace gas passes down the inner face of the drying shaft. With this design of shaft, owing to the small opening between firebrick rings, the coal is more or less stagnant in this space, with the result that a certain amount of combustion takes place on the surface; but as this burning surface cannot mix in with the main body of coal flowing down the chute it has very little influence on the drying. Also, the particles of burning coal deposited in the small spaces between the louvres or blocks by the passing flue gases are less effective in drying the body of

the coal than they might be, as they simply burn on the coal surface without mixing in with the coal. It will be understood that this surface-burning between the louvres probably tends to be less effective in its drying, as the fines in the coal increase, and would give better results possibly in some installations using selected brown coal.

This inherent defect of the louvred wall drying shaft led to the adoption of the design of shaft shown in Fig. 10. This shaft consists of a staggered arrangement of firebrick walls set in the combustion chamber at angles such that the coal, during its passage down the dryer, is compelled to take a zig-zag path, with the result that a mixing action is obtained. Moreover, a larger surface is exposed to the action of surface burning, to the reception of radiant heat from the hot surface gases and firebrick walls, and for the lodgement of burning coal particles from the gas, with the result that a drying shaft has been evolved which appears to promise more effective drying than the earlier louvred type.

Preliminary trials of this drying shaft and mechanical step grates recently installed on a boiler in the existing boiler house have been made, and have shown that it is possible under operating conditions to burn 95.2 lb. of Yallourn brown coal per hour per square foot of mechanical grate, corresponding to a liberation of 294,500 B.Th.U. per hour per square foot of grate. The coal used on these tests was crushed Yallourn brown coal, with approximately 10 per cent. over $2\frac{1}{2}$ in. in size and 40 per cent. under $\frac{1}{4}$ in. in size and containing 64 per cent. water. Under operating conditions the unit, which is equipped with both forced and induced draft fans, was operated with an air pressure of 1.0 in. of water column in the chamber under the grate and 0.35 in. of water column suction in the combustion chamber. The trials were made when the unit was operating on cold air before the completion of the air pre-heater, hence considerably better results are anticipated in the future, when hot air under pressure is supplied to the furnace.

It has been found that a positive pressure in the air chamber under grates substantially increases the capacity of a boiler plant, under which is burnt raw brown coal, but in the case of the compartment type chain grate, positive pressure also introduces a very troublesome situation in the boiler house, inasmuch as large quantities of sparks and dust are blown out from the clearance

spaces between the moving and fixed portions of the grate. With step grates, however, the pressure chamber can be more effectively sealed.

As previously mentioned, in view of the success attained in burning Yallourn raw coal in this trial unit, it is proposed to adopt the same general design for the first section of boiler plant to be installed in the second boiler house at Yallourn.

Arrangement of Boiler Plant

The illustrations (Figs. 11 and 12) indicate the proposed arrangements of boiler units. There are to be eight boiler units in

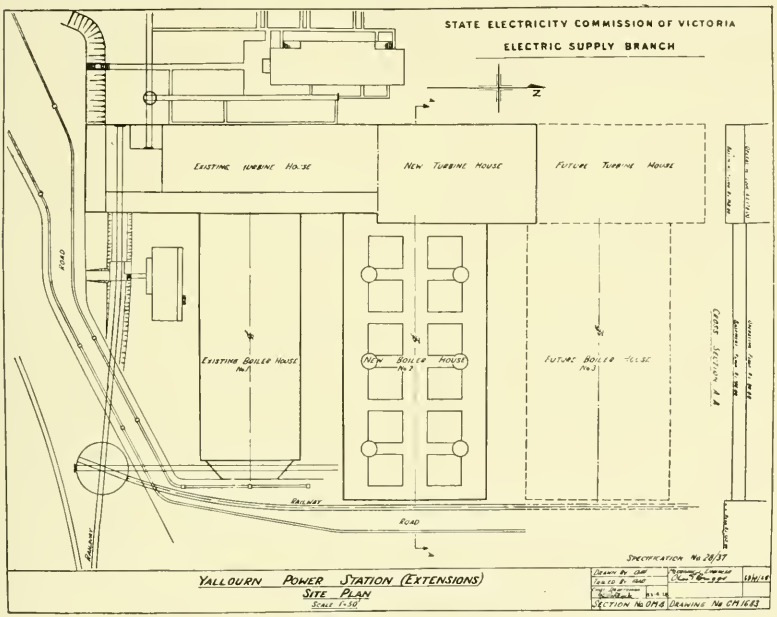

Fig. 11. Site plan of Yallourn Power Station.

the first instalment of the new boiler house, but the completed boiler house is being designed to accommodate twelve boiler units, each with a normal evaporation of 75,000 lb. of steam per hour from feed water, at a temperature of 280°F., into steam at a pressure of 270 lb. per sq. in. (gauge) and a temperature of 700°F. at the superheater stop valve. The units are to be designed to burn Yallourn brown coal containing 64 per cent. moisture, and will be equipped with mechanical step grates and drying shafts.

An unusual feature in the specification for the new boiler plant is included in the section dealing with performance guarantees

of the proposed plant, in that all guarantees of efficiency have been replaced by guarantees of flue gas temperatures. The grates are to be provided under a separate specification to that covering

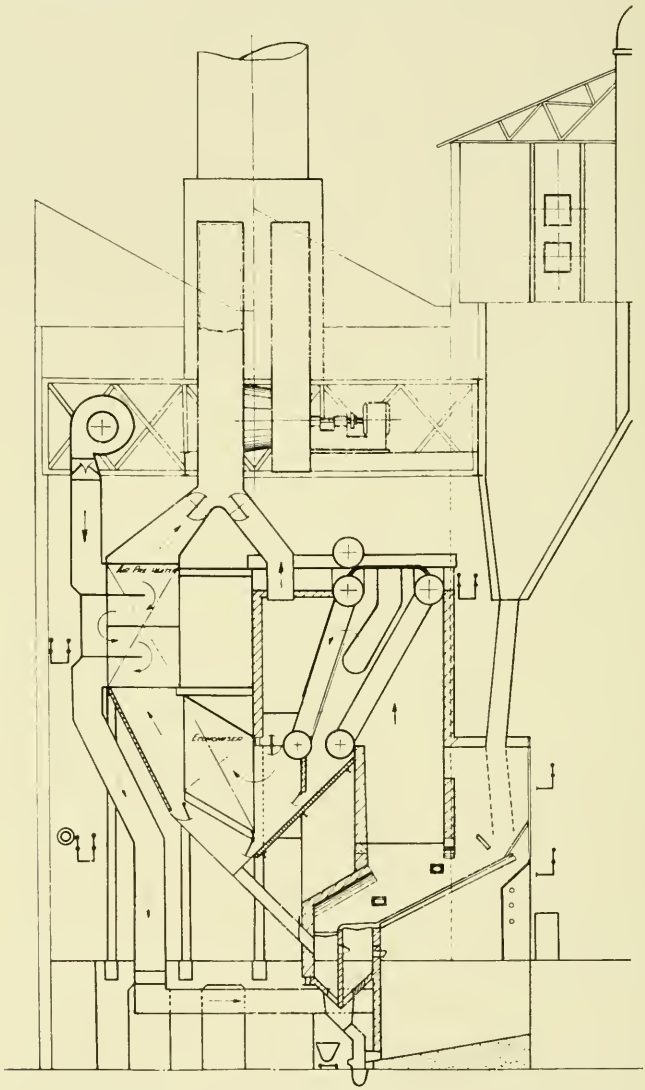

Fig. 12. Arrangement of proposed boiler unit for the Yallourn extension boiler house.

the rest of the boiler plant, and the tenderers for the boiler unit have been assured that there will be a sufficiency of hot gases to

enable the boiler to develop its guaranteed capacity with the grates. The grates to be supplied by the grate contractor will be capable of burning a certain weight of Yallourn brown coal, while emitting furnace gas, with an excess air corresponding to a specified percentage of CO_2 measured at the point of entering the boiler heating surface, and when the combustible in the refuse and the CO in the flue gases are within fixed limits.

The elimination of the usual guarantees of overall boiler plant efficiency avoids the necessity for an assumption by the tenderer of the "unaccounted for" losses incidental to burning a fuel which differs considerably from the fuels commonly used in Australia.

Upon testing a boiler on Yallourn brown coal and computing the heat balance in the usual way, the "unaccounted for" losses due to radiation, combustible in ashes, and in the particles carried away by the gases leaving the furnace, are found to be much higher than is customary in black coal practice. The excess is attributed to the loss in flying particles of combustible, and tests made indicate that this loss varies from 3 per cent. at low ratings, up to 12 per cent. at higher ratings when units are not equipped with air pre-heaters. With air pre-heaters this "unaccounted for" loss is reduced to about half these values when the air is pre-heated to the region of 400°F.

Without an appreciation of this characteristic of brown coal burning, the reverse might be expected on account of the relatively low furnace temperatures and consequent low radiation losses obtaining when burning raw brown coal.

It was not difficult to arrive at a decision to incorporate air pre-heaters in the new boiler plant for Yallourn power station extensions.

Apart from the now generally accepted principle that modern steam practice has reached as to the economic soundness of employing the boiler exit gases to pre-heat the air for the furnaces while the feed water is heated by steam drawn from stages in the turbines, there was a feeling that heated air would have particular advantages in its application to brown coal burning.

These expectations have been largely realised in a few trials conducted on a regenerative air pre-heater of the rotating type installed some six months ago on one of the original boilers equipped with the previously described combination of chain grates and supplementary stationary step grates. Air is supplied at approximately 400°F.

TABLE V. TABLE OF YALLOURN BOILER OUTPUTS WHEN BURNING MORWELL AND YALLOURN BROWN COAL.

Grate Arrangement.	Class of Coal.	Normal working output			Maximum continuous output		
		Output of steam lbs. per hour.	Lbs. of coal burned per sq. ft. of grate per hour.	B.Th.U. liberated per sq. ft. grate area per hour.	Output of lbs. per hour.	Lbs. of coal burned per sq. ft. of grate per hour.	B.Th.U. liberated per sq. ft. area per hour.
Travelling grate only	Morwell coal (45 to 50 per cent. moisture), screened between limits of $\frac{1}{4}''$ and $\frac{1}{2}''$	75,000	60·0	301,500	100,000	83·5	417,500
Travelling grate only	Yallourn coal (64 per cent. moisture), screened between limits of $\frac{1}{4}''$ and $2''$	42,000	65·5	229,500	55,000	93·5	289,000
Travelling grate and flue gas dryer ...	Yallourn coal (64 per cent. moisture), screened between limits of $\frac{1}{4}''$ and $1\frac{1}{2}''$	55,000	89·1	275,500	72,000	112·0	346,100
Travelling grate with fixed inclined extension grate ...	Yallourn coal (64 per cent. moisture), coal crushed but with coal over $2\frac{1}{2}''$ in size screened off	65,000	70·5	217,040	74,040	77·6	239,600
Travelling grate with fixed inclined extension grate and air pre-heated to 400 degrees Fah. ...	Yallourn coal (64 per cent. moisture), coal crushed to below 4" in size. No screening...	70,000	72·3	223,500	77,000	77·1	238,200
Inclined step grate and vertical drying shaft (air pre-heater not in commission).	Coal crushed to below 4" in size. No screening	70,000	74·1	229,200	90,000	95·3	294,500

NOTE.—The inclined extension grates are included but drying shafts and flue gas dryers are excluded in deducing grate areas. The fixed step grates at the end of the mechanically moving grates are excluded in all cases.

Experience gained with this boiler unit has demonstrated that air pre-heating is extremely beneficial in its application to brown coal burning at Yallourn, where the fuel is of low grade, variable in texture and high in moisture content, namely 64 per cent., inasmuch as it increases the flexibility of the boiler, enabling steam to be raised more quickly than with cold air, it increases the grate capacity 15 per cent. to 20 per cent., and it decreases the loss due to the unburnt particles of coal carried off in suspension by the furnace gases.

Table V briefly summarises the outputs from the present boilers at Yallourn, obtained with various forms of apparatus which have been used in the combustion of the Morwell and Yallourn brown coals in the several stages of development. This table clearly illustrates the ease with which well-graded brown coal, having moisture contents up to 50 per cent., can be burnt efficiently, compared with the extreme difficulty of obtaining anything like proportionate results from 64 per cent. moisture Yallourn coal of wide textural variability. It further demonstrates how these difficulties, by the adoption of suitable methods of a reasonably simple character can be overcome, so that the success from a combustion aspect of any scheme based on the utilisation of brown coal, such as Yallourn brown coal, is definitely assured.

Turning now to other means for dealing with brown coal, it may be mentioned that in the course of brown coal investigation the Commission has given a great deal of thought to the possible advantages to be gained by adopting some system involving the partial pre-drying of Yallourn coal by means external to the boiler plant before introducing it to the furnaces.

The coal, having been partially pre-dried, can then be burned in either of two ways :—

1. As pulverised partly dried brown coal, introduced into the furnace through burners in the ordinary way.
2. As partly dried brown coal of a texture depending upon the degree of dryness introduced upon inclined step grates specially designed for the purpose.

The latter method has, so far, not been developed, and no doubt would involve a good many uncertainties, which, however, could probably be successfully solved in the process of time.

The application of a pulverised fuel system to brown coal combustion has already been tried, not only experimentally by the

Commission, but by other authorities both commercially and experimentally with, in many cases, eminent success.

The Commission's efforts were principally directed towards ascertaining the characteristics and difficulties peculiar to brown coal in the process of pulverising and burning. It was established that brown coal, as distinct from ordinary black coals, necessitates to an extent dependent upon the moisture content of the prepared coal, special adaptations of the normal standard pulverised fuel appliances, in respect to pulverising mills, storage bins and transportation pipes, screens, feeders, etc. These adaptations, however, are of minor importance compared with the special treatment of the drying process.

Classification of Dryers

In designing a drying plant the degree of dryness to be aimed at will depend upon the subsequent treatment of the coal; generally speaking, it is desirable to dry brown coal down to from 15 to 18 per cent. moisture content for use in a "bin and feeder" or central system, and from 30 to 35 per cent. moisture for use in a "direct firing" or unit system. Beyond these limits difficulties become accentuated.

Coal drying apparatus may be divided broadly into two classes :

1. Drying by steam.
2. Drying by hot flue gas.

Class 2 may certainly be subdivided into "direct" and "indirect." Possibly Class 1 may be similarly subdivided, although nothing of any commercial magnitude has so far been done to develop "direct" steam drying.

Class 2 may be further subdivided into "high-temperature" and "low-temperature" flue gas. The early Yallourn dryers already described belonged to the "low-temperature direct" subdivision. In other parts of the world coal dryers have been used of a composite class, combining features of both classes.

Apart from the early Yallourn dryers, the Commission has confined its actual experience to the most practicable systems now in use, namely :—

1. Steam drying by indirect means, such as has been in use at Yallourn Briquette Factory for several years, employing dryers identical with those almost invariably used in modern brown coal briquette factories in Germany, and consisting

mainly of large steel drums slightly inclined, revolving slowly in trunnions while steam is introduced to the interior at a low pressure and while the coal, after having been crushed to a fine texture, gradually flows along 4-in. tubes which extend from end to end of the drums.

2. Drying by direct contact with hot flue gas, as was the system employed in a small plant installed some five years ago in proximity to Newport power station, for the purpose of drying and pulverising brown coal used in experiments relating to the combustion of pulverised brown coal in locomotives, and on one of the stationary water tube boilers at Newport power station.

The type of dryer employed in this case was that commonly supplied at that time by the Fuller-Lehigh Co. Particulars of this plant and the experiments referred to are reported in detail in Bulletin No. 1, issued by this Commission in 1926.

The Commission's investigations into the best system of combustion to be adopted for the proposed extensions of generating plant took fully into account the use of dried coal burned in pulverised form or otherwise.

At first sight, steam drying has an attraction for a power supply undertaking, by reason of the so-called surplus energy which may be generated by back pressure turbines reducing the high pressure steam from the boilers to a low pressure of approximately 40 lb. per sq. in., such as is suitable for supplying to the dryers.

The amount of surplus energy obtained in this way, however, is relatively small when the amount of coal to be dried is for the power station requirements only, and by reason of the low cost of raw brown coal, the resulting reduction in the power station "variable charges" was estimated to be slightly more than counterbalanced by the additional "standing or fixed charges" which the drying plant would entail.

If, however, there were a market for dried coal considerably beyond the power station requirement, a dried coal system of firing for the power station would be much more favourable, and the rate of improvement would be very rapid, as the output of dried coal increased alternatively the cost of dried coal would decrease if the cost of generation, apart from the cost of coal, remained as before.

Comparing a dried coal system based on "direct" drying with one based on steam drying, it was found that the two systems

would be approximately equal on an economic basis, so long as the outputs were relatively small; moreover, the "direct" system appeared to present difficulties and undesirable features which the "steam" system would not possess. An economic superiority of the steam system comes into evidence as the dried coal requirements increase.

The ultimate decision in regard to the power station extensions was that, for the present extensions at any rate, it would not be advantageous to pre-dry the coal by an external process prior to its introduction to the boiler furnaces.

ZUSAMMENFASSUNG

Die Braunkohlenlager im Staate Viktoria, Australien, umfassen das "Latrobe Tal"-Gebiet, eines der reichsten Kohlenvorkommen der Welt. Dieses Gebiet wird gegenwärtig von der State Electricity Commission von Viktoria, einer Regierungsorganisation, die ein Kraftwerk und eine Brikettfabrik dort errichtet hat, ausgebeutet. Die in den verschiedenen Teilen des Latroben Tales vorgefundene Kohle wechselt wesentlich in ihrer physikalischen und chemischen Beschaffenheit, sodass das Kraftwerk, welches anfänglich die Morwell-Kohle von 45 bis 50% Feuchtigkeit feuerte, jetzt die Yallourn-Kohle mit einer Feuchtigkeit von 64% feuert. Die Electricity Commission hat die Erfahrung gemacht, dass Braunkohle mit 45 bis 50% Feuchtigkeit auf Wanderrosten mit unterteilter Luftzuführung mit guten Resultaten verfeuert werden kann, falls gleichzeitig ein durch Unterwindventilatoren erzeugter Luftdruck unter dem Rost besteht. Es geht aus Versuchen hervor, dass man stündlich 407,7 kg Morwell-Kohle pro Quadratmeter Rost verfeuern kann, was einer Befreiung von 1 132 000 WE pro Quadratmeter Rost pro Stunde entspricht. Umfassende Versuche sind durchgeführt worden, um die Leistung der Roste mit unterteilter Luftzuführung bei der Verbrennung von Yallourn-Kohle mit einer Feuchtigkeit von 64% zu erhöhen. Die anfänglichen Entwickelungen hatten zum Ziel, die Kohle vor Eintritt in die Feuerung durch die Kesselabgase zu trocknen, aber aus verschiedenen in dem Artikel angeführten Gründen ist diese Form von Vortrocknungsapparat durch Treppenroste ersetzt worden, welche die Kohle nach ihrem Eintritt in die Feuerung, aber vor ihrer Verteilung auf dem Rost mit unterteilter Luftzuführung vorwärmen und teilweise trocknen. Aus einer Anzahl auf Erfahrungen mit einer Versuchseinheit gestützter Gründe wurde beschlossen, in der Yallourner Kesselhauserweiterung mechanische Vorschubtreppenroste mit vorgebauten Trockenschächten einzubauen. Diese projektierte Kesselhauserweiterung liefert den Dampf für drei 25 000 kW-Turbinen, wodurch die installierte Leistung des Kraftwerks Yallourn auf 150 000 kW erhöht werden wird.

DIE KOHLENWIRTSCHAFT ÖSTERREICHS

(THE COAL INDUSTRY IN AUSTRIA)

VEREIN DER BERGWERKSBESITZER ÖSTERREICHS

DR. A. GSTÖTTNER

Paper No. A3

CONTENTS

AUSTRIAN COAL—IMPORTED COAL—COAL CONSUMPTION—INTERNAL MARKET FOR AUSTRIAN BROWN COAL
RÉSUMÉ

Dem heutigen Oesterreich sind von den ausgedehnten Kohlenlagerstätten des früheren Reiches nur bescheidene Kohlenvorkommen verblieben, so dass der Bedarf Oesterreichs an mineralischen Brennstoffen heute aus der Inlandsproduktion beiweitem nicht gedeckt werden kann. Ueberdies sind in Oesterreich vorwiegend Braunkohlen vorhanden, während Steinkohle nur vereinzelt gefördert wird. Oesterreich ist sonach insbesondere in Steinkohle, die auch in bedeutenden Mengen eingeführt wird, auf das Ausland angewiesen. In diesen Mengen sind auch grössere Quantitäten von Spezialkohlen enthalten (wie z.B. Gaskohle), die in Oesterreich überhaupt nicht gewonnen werden. Ferner ist zu bemerken, dass in Oesterreich derzeit weder Hochofenkoks noch auch Brikette erzeugt werden.

Was nun die Kohlenversorgung Oesterreichs betrifft, so ist vorweg festzustellen, dass der österreichische Markt von fast allen ausländischen Grossrevieren beliefert wird. Vor allem ist in Oesterreich die oberschlesische Steinkohle im Hausbrand gut eingeführt und hat nach wie vor den grössten Anteil an der Einfuhr; es folgen dann die Tschechoslowakei und Deutschland, sowie mit kleineren Mengen von Stein- und Braunkohlen das Saargebiet, Holland, England, Ungarn und Jugoslawien.

Ein Ueberblick auf die Gestaltung des österreichischen *Kohlenkonsums* zeigt, dass der Verbrauch in den letzten Jahren—je nach

der Konjunkturlage—Schwankungen ausgesetzt war. Der Anteil der *Inlandskohle* (zirka 3 Millionen Tonnen jährlich) besteht überwiegend aus *Braunkohle,* zumal die österreichische Steinkohlenförderung bisher pro Jahr höchstens 170 000 Tonnen erreicht hat. Ausser den in nachstehender Tabelle erwähnten Kohlenmengen werden noch jährlich zirka 400 000 Tonnen *Gaskoks* verbraucht, der jedoch durchwegs aus *Auslandskohle* hergestellt wird, also in den Importmengen bereits enthalten ist.

Kohlenverbrauch Oesterreichs in metrischen Tonnen (à 1 000 kg).

Jahr:	1922	1923	1924	1925	1926	1927
Inlands-kohle	3 277 353	2 803 508	2 922 288	3 157 736	3 066 775	3 161 295
Auslands-kohle	5 809 781	5 023 394	5 764 855	5 271 680	5 124 600	5 601 398
Gesamt-verbrauch	9 087 134	7 826 902	8 687 143	8 429 416	8 191 375	8 762 693

Die *importierten* Mengen setzen sich aus folgenden Arten von Brennstoffen zusammen:

Jahr:	1922	1923	1924	1925	1926	1927
Steinkohle	4 019 435	3 755 209	4 537 919	4 252 789	4 141 615	4 568 509
Braun-kohle	1 403 813	865 010	847 533	505 483	493 275	459 226
Koks	386 533	403 175	379 403	513 408	489 710	573 663

Die *Kohlenausfuhr* Oesterreichs ist von ganz untergeordneter Bedeutung und bewegt sich hauptsächlich nach Ungarn, Jugoslawien, Deutschland und zeitweise auch nach Italien. Wiener Gaskoks wird nach diesen Ländern und seit einiger Zeit auch nach der Schweiz, Bulgarien etc. exportiert.

Die *Kohlenausfuhr Oesterreichs* betrug in metrischen Tonnen in den Jahren

	1923	1924	1925	1926
Braunkohle	32 759	13 880	21 282	47 684
Steinkohle	22 416	6 504	449	2 851
Koks (Gaskoks)... ...	11 809	19 689	41 343	146 144

Die Kohlenausfuhr Oesterreichs könnte wesentlich gesteigert werden, wenn nicht gerade die in Betracht kommenden, ebenfalls kohlenarmen Nachbarländer (Jugoslawien, Ungarn) teils durch Zölle und Einfuhrtaxen, teils durch tarifarische Massnahmen die Einfuhr von Kohle erschweren würden. Für den Export kämen in erster Linie steirische Braunkohlen in Frage.

Nachstehende Tabellen zeigen den Anteil der einzelnen Auslandsreviere an der Kohleneinfuhr Oesterreichs in den Jahren 1922 bis 1927.

Kohleneinfuhr Oesterreichs (nach einzelnen Ländern und Revieren) in metrischen Tonnen.

Jahr:	1922	1923	1924	1925	1926	1927
Tschechoslowakische Republik.						
Steinkohle:						
Ostrau ...	643 749	492 379	957 828	907 183	1 014 398	1 177 950
sonstige	268 560	170 719	187 590	116 460	136 330	136 169
Koks:						
Ostrau ...	129 942	273 224	247 981	252 687	171 097	241 516
sonstiger	2 116	6 299	13 403	2 084	1 294	1 342
Braunkohle:	1 357 379	795 739	713 944	315 912	293 890	281 445
Polen.						
Steinkohle:						
Dombrowa	468 208	510 457	269 102	239 322	270 551	367 482
Ostoberschlesien	2 280 537[1]	2 273 589	2 683 365	2 443 520	2 330 704	2 507 303
Braunkohle:	6 636	23	—	—	—	—
Koks: ostoberschlesischer	39 390[1]	58 082	49 603	39 670	40 088	46 501
Deutschland.						
Steinkohle:						
Oberschlesische ...	—	—	20 191	146 729	145 186	134 203
Ruhrkohle	—	555	123 026	172 572	216 499	200 176
sonstige ...	87 138	28 911	29 399	31 504	7 747	5 403
Koks:						
Oberschlesischer ...	—	7 465	28 561	38 716	44 524	46 460
Ruhr ...	186 690	15 951	10 697	151 038	202 847	215 230
sonstiger...	18 949	5 030	24 243	28 023	28 754	21 233
Braunkohle	22 238	4 920	29 750	66 447	67 438	64 484
Saarrevier.						
Steinkohle ...	218 861	184 668	228 913	178 676	5 742	35 893
Koks ...	—	1 923	2 938	743	731	1 054
Holland.						
Steinkohle ...	11 786	1 080	2 153	620	393	220
Koks ...	2 917	182	185	44	—	—
England.						
Steinkohle ...	39 635	92 091	36 025	14 361	11 573	1 082
Koks ...	4 176	34 757	1 488	403	163	—
Belgien.						
Steinkohle ...	195	205	185	448	175	151
Koks ...	107	196	—	—	—	—
Frankreich.						
Steinkohle ...	766	555	142	86	—	95
Koks ...	2 246	66	304	—	—	—
Jugoslawien.						
Braunkohle	15 212	63 531	96 283	58 940	38 011	32 367
Ungarn.						
Braunkohle	2 348	797	7 556	64 184	93 936	80 930
Koks ...	—	—	—	—	16	32
Steinkohle ...	—	—	—	—	—	2 382

[1]Für 1922 Gesamtoberschlesien.

Der *prozentuale Anteil* des Inlands und der wichtigsten Auslandsstaaten an der Kohlenbelieferung Oesterreichs stellte sich in den letzten Jahren wie folgt:

Anteil am Kohlenverbrauch Oesterreichs (in Prozenten).

	1922	1923	1924	1925	1926	1927
Inlandskohle	36,0	35,8	33,6	37,5	37,4	36,1
Polen	30,7	36,3	34,5	32,3	32,2	33,3
Tschechoslowakische Republik	26,3	22,2	24,4	18,9	19,7	21,0
Deutschland	3,5	0,8	3,1	7,5	8,7	8,0

Dieser Tabelle ist zu entnehmen, dass die Inlandskohle ihren Anteil nach vorübergehender Besserung knapp beibehalten konnte. Insbesondere an der Steigerung des österreichischen Kohlenverbrauches im Jahre 1927 hatte die Inlandskohle nur einen geringen Anteil, indem die Lieferungen der österreichischen Kohlenwerke von 3,07 Millionen Tonnen auf 3,16 Millionen Tonnen anstiegen. Dagegen hat sich infolge der erheblichen Zunahme des Verbrauches (der Gesamtbedarf stieg von 8,19 pro 1926 auf 8,76 Millionen Tonnen pro 1927) die Einfuhr fremder Kohle von 5,12 auf 5,60 Millionen t erhöht. Auch im Vorjahre bestand bei den österreichischen Grossverbrauchern im allgemeinen das Bestreben, an den alten Bezugsquellen festzuhalten und der Uebergang von der Steinkohlen- zur Braunkohlenfeuerung machte nur sehr geringe Fortschritte.

Die Organisation des österreichischen Kohlenbergbaues ist seit Jahren bemüht, eine Ausdehnung des Verbrauches an Inlandskohlen zu propagieren. Wenn in mancher Beziehung bereits ein Erfolg zu verzeichnen ist, so bleibt wohl noch sehr viel zu tun übrig. Die Wiener Industrie verwendet noch immer mit Vorliebe ausländische Steinkohle, der Hausbrand feuert nur in Steiermark und Oberösterreich überwiegend Inlandskohle, während in Wien und Niederösterreich nach wie vor die ostoberschlesische Kohle als Hausbrandmarke dominiert. Die österreichischen Glanzkohlen haben einen Heizwert bis zu 5 600 Kalorien, die Braunkohlen von 4 000 bis 5 000. Der Köflacher Lignit wird seit einiger Zeit im Wege des Fleissnerschen Trockenverfahrens veredelt und auch diese Kohle (Heizwert zirka 5 300 Kalorien) wäre sehr geeignet, die ausländische Steinkohle zu ersetzen. Der Absatz liegt in Trockenkohle auch sehr günstig, doch bedarf es auch in diesem Belange noch einer intensiven Propaganda, um die Verbraucher auf die Vorteile dieser veredelten Kohle aufmerksam zu machen. Unsere Steinkohlenmarken (Lunzer Schmiedekohle und Grünbacher Steinkohle) haben ebenfalls ständig mit Absatzschwierigkeiten zu

kämpfen, da am österreichischen Markte die Rossitzer Schmiedekohle von jeher gut eingeführt ist und die Grünbacher Steinkohle naturgemäss in erster Linie gegen die polnisch-oberschlesischen Grossproduzenten konkurrieren muss.

Es ist von Interesse festzustellen, wie sich bei den Verbrauchergruppen das *Verhältnis zwischen Inlands- und Auslandskohle* stellt. Diesbezüglich sei auf nachstehende Tabelle verwiesen, welche die amtlichen Daten für das Jahr 1926 enthält.

Es ist schon im Interesse der österreichischen *Handelsbilanz,* die aus dem Titel der Kohleneinfuhr stark belastet erscheint, sehr bedauerlich, dass die österreichischen Verbraucher aus alter Gewohnheit an den ausländischen Bezugsquellen festhalten und nach wie vor sehr bedeutende Mengen von Kohle nach Oesterreich eingeführt werden.

Im Jahre 1926 stellte sich die *Handelsbilanz* wie folgt:

	Gesamteinfuhr	Gesamtausfuhr	
	Wert in Schillingen		
	2 844 553 000	1 744 930 000	
Das Passivum betrug sohin	...	...	S 1 099 623 000

Die *Kohlenhandelsbilanz* weist für das gleiche Jahr folgende Ziffern auf: Einfuhrwert 205 228 000 S, Ausfuhrwert 8 332 000 S, sodass das Passivum also 196 896 000 S betrug. Nicht viel weniger als ein Fünftel des Passivums der Gesamtbilanz entfallen auf die Kohleneinfuhr. Diese besteht noch immer zu einem nicht geringen Teil aus *Braunkohle* (im Jahre 1927 459 000 t), deren Import ganz überflüssig erscheint, da diese aus Böhmen, Jugoslawien und Ungarn sowie auch aus Deutschland stammende Kohle ohneweiteres durch heimische Braun- und Glanzkohlen ersetzt werden könnte.

Unter diesen Umständen war es dem österreichischen Kohlenbergbau bisher nicht möglich, seine *Produktion* wesentlich auszudehnen. Oesterreichs Bergbau verfügt über ein *Kohlenvermögen* von zirka 700 Millionen Tonnen. Die bisherige Jahresproduktion von nicht viel über 3 Millionen Tonnen könnte schon mit den derzeitigen technischen Einrichtungen binnen kurzer Zeit auf mindestens 4,5 Millionen Tonnen gebracht werden, wenn es gelänge, einen entsprechenden *Absatz* sicherzustellen. Um es aber den grossen Kohlenbergbauen Steiermarks und Oberösterreichs trotz ihrer Entfernung von den *Hauptverbrauchszentren* (Wien und Niederösterreich) möglich zu machen, mit den ausländischen

ANTEIL VON INLANDS- UND AUSLANDSKOHLE AM GESAMTVERBRAUCH (IN TONNEN)

Verbrauchergruppe	Inland			Ausland				Gesamtmenge			
	Steinkohle	Braunkohle	Zusammen	Steinkohle	Braunkohle	Koks	Zusammen	Steinkohle	Braunkohle	Koks	Zusammen
Verkehr	362	351 954	352 316	1 380 638	1 060	665	1 382 363	1 381 000	353 014	665	1 734 679
Gaswerk Wien	20	—	20	517 799	—	—	517 799	517 819	—	—	517 819
Elektrizitätswerk Wien	31 615	505 632	537 247	139 189	68 451	—	207 640	170 804	574 083	—	744 887
Gas-, Wasser- und Elektrizitätswerke in den Ländern	102	26 300	26 402	88 762	2 318	402	91 482	88 864	28 618	402	117 884
Gas-, Wasser- und Elektrizitätswerke zusammen	31 737	531 932	563 669	745 750	70 769	402	816 921	777 487	602 701	402	1 380 590
Hausbrand Wien*	4 547	184 676	189 223	687 919	7 792	59 761	755 472	692 466	192 468	59 761	944 695
Hausbrand in den Ländern*	12 518	287 005	299 523	336 610	112 234	29 651	478 495	349 128	399 239	29 651	778 018
Hausbrand zusammen*	17 065	471 681	488 746	1 024 529	120 026	89 412	1 233 967	1 041 594	591 707	89 412	1 722 713
Landwirtschaft	96	1 200	1 296	35 304	2 066	811	38 181	35 400	3 266	811	39 477
Industrie—											
Nahrungsmittel	1 783	76 262	78 045	198 697	43 413	5 804	247 914	200 480	119 675	5 804	325 959
Eisen- u. Metall	40 075	608 970	649 045	182 814	64 745	352 863	600 422	222 889	673 715	352 863	1 249 467
Bergbau (einschliesslich Eigenbedarf des Kohlenbergbaues)	6 290	281 023	287 313	31 019	13 431	6 971	51 421	37 309	294 454	6 971	338 734
Salinen	—	61 263	61 263	30	—	—	30	30	61 263	—	61 293
Chemische Industrie	6 781	55 187	61 968	110 904	6 449	6 508	123 861	117 685	61 636	6 508	185 829
Keramische und Glasindustrie	10	51 302	51 312	10 088	34 566	515	45 169	10 098	85 868	515	96 481
Baustoffindustrie	15 572	99 557	115 129	120 845	53 729	22 497	197 071	136 417	153 286	22 497	312 200
Tabakindustrie	1 174	5 798	6 972	846	—	18	864	2 020	5 798	18	7 836
Textilindustrie	15 440	23 112	38 552	181 351	20 960	2 737	205 048	196 791	44 072	2 737	243 600
Lederindustrie	477	24 852	25 329	11 684	1 743	65	13 492	12 161	26 595	65	38 821
Papierindustrie	18 434	250 437	268 871	100 377	59 226	245	159 848	118 811	309 663	245	428 719
Holz- und sonstige Industrie	99	16 850	16 949	6 739	1 092	197	8 028	6 838	17 942	197	24 977
Landwirtschaft u. Industrie zusammen	106 231	1 555 813	1 662 044	990 698	301 420	399 231	1 691 349	1 096 929	1 857 233	399 231	3 353 393
Gesamtbelieferung	155 395	2 911 380	3 066 775	4 141 615	493 275	489 710	5 124 600	4 297 010	3 404 655	489 710	8 191 375

* Einschliesslich Kleingewerbe.

Kohlenkonzernen erfolgreich zu konkurrieren, müssten eben Tarifmassnahmen zu Hilfe kommen.

Es muss zugegeben werden, dass die Lage des österreichischen Kohlenbergbaues auch durch das *Fehlen eines Syndikates* erschwert wird. Diesbezüglich wurden in den letzten Jahren zwar wiederholt Verhandlungen gepflogen, doch ist es bisher nicht gelungen, die heimischen Kohlenproduzenten in einer wirtschaftlichen Organisation zusammenzuschliessen. Allerdings stellen sich in diesem Belange bedeutende Schwierigkeiten entgegen, die auf die zerstreute Lage der Gruben und die Verschiedenartigkeit der gewonnenen Kohlen zurückzuführen sind.

Aus der österreichischen Bergbaustatistik ist zu ersehen, dass sich die Zahl der Kohlenwerke in den letzten Jahren stark verringert hat. Die in den Kriegsjahren in Betrieb gesetzten Gruben sind, soweit sie nicht lebensfähig waren, längst wieder stillgelegt und auch die Konzentration hat gewisse Fortschritte gemacht.

Nachstehende Tabellen geben Aufschluss über die Kohlenproduktion Oesterreichs, Zahl der Betriebe, Belegschaft etc.

Kohlenproduktion Oesterreichs in Tonnen in den Jahren:

A. Steinkohle.

1913	1919	1920	1921	1922
87 470	90 472	132 864	137 633	165 727
1923	**1924**	**1925**	**1926**	**1927**
157 650	171 959	145 200	157 308	175 601

B. Braunkohle.

1913	1919	1920	1921	1922
2 621 277	2 217 335	2 696 954	2 797 077	3 135 902
1923	**1924**	**1925**	**1926**	**1927**
2 685 467	2 785 816	3 033 378	2 957 728	3 064 068

Insgesamt stellte sich die Kohlengewinnung (Stein- und Braunkohle zusammen) in den vorgenannten Jahren wie folgt (in Tonnen):

1913	1919	1920	1921	1922
2 708 747	2 307 807	2 829 818	2 934 710	3 301 629
1923	**1924**	**1925**	**1926**	**1927**
2 843 117	2 957 775	3 178 578	3 115 036	3 239 669

Jahr:	Zahl der Betriebe	Beschäftigte Personen	Wert der Jahresproduktion 1 000 *Kronen*
A. Steinkohlenbergbau.			
1913	4	585	1 180
1919	12	1 358	23 833
1920	18	2 077	225 473
1921	24	2 455	1 019 891
1922	19	2 322	36 783 839
1923	15	1 922	75 634 704

Jahr:	Zahl der Betriebe	Beschäftigte Personen	Wert der Jahresproduktion
			Schillinge
1924	15	1 838	7 260 959
1925	11	1 574	4 997 871
1926	8	1 169	5 085 039
B. Braunkohlenbergbau.			1 000 *Kronen*
1913	40	12 147	23 473
1919	56	16 498	265 846
1920	78	18 507	1 545 918
1921	81	20 888	5 990 138
1922	76	21 103	418 520 355
1923	77	18 634	650 715 475
			Schillinge
1924	77	16 692	58 242 076
1925	67	14 968	60 986 467
1926	52	14 153	57 463 688

Die österreichische Kohlenproduktion ist in der Hauptsache auf wenige grössere Unternehmungen beschränkt. In Steiermark—wie überhaupt in Oesterreich—ist die Oesterreichisch-Alpine Montangesellschaft Hauptproduzentin. Diese Gesellschaft hat vor kurzem auch die Aktienmehrheit der Graz-Köflacher Eisenbahn- und Bergbau-Gesellschaft übernommen, wodurch ihre Produktion noch um mehr als 30 000 t monatlich gestiegen ist. Auch die Graz-Köflacher Gesellschaft betreibt in Steiermark Braunkohlengruben. In Oberösterreich liegt die Produktion des dortigen sehr ausgedehnten Lignit-Vorkommens am Hausruck bei der Wolfsegg-Traunthaler Kohlenwerks-A.G. In Niederösterreich ist die Grünbacher Steinkohlenwerke A.G. die grösste Kohlenproduzentin, die bei Grünbach am Schneeberg das einzige grössere Steinkohlenvorkommen Oesterreichs abbaut. Die sonstigen Steinkohlenvorkommen Niederösterreichs (die anderen Bundesländer haben keine Steinkohlenvorkommen aufzuweisen) sind kleinere Schmiedekohlenvorkommen in der Lunzer Gegend. Im Burgenlande besteht die Braunkohlenbergbau-Gewerkschaft Zillingdorf, welche einen kleinen Bergbau auf Lignit in Niederösterreich und anschliessend die ergiebigen Tagbaue bei Neufeld im Burgenlande betreibt. Die Kuxe dieser Gewerkschaft sind restlos im Besitz der Gemeinde Wien, welche die geförderte Kohle ausschliesslich in der nahegelegenen Kraftzentrale in Ebenfurth in elektrische Energie umwandelt, die nach Wien weitergeleitet wird. Zirka ein Drittel des in Wien verbrauchten Stomes wird mit Zillingdorfer Kohle erzeugt.

Bezüglich der *Kohlenbergbauunternehmungen Oesterreichs* sei auf nachstehende Zusammenstellung verwiesen, welche alle Bergbaue umfasst, die in Betrieb stehen, und auch deren Produktion für das Jahr 1927 wiedergibt:

Kohlenproduktion der österreichischen Bergbaue im Jahre 1927 (in Tonnen):

	Produktion.
A. Steinkohle.	
Revier Wiener Neustadt (Niederösterreich):	
Grünbacher Steinkohlenwerke A.G. in Grünbach am Schneeberg	167 317
Revier St. Pölten (Niederösterreich):	
Schrambacher Steinkohlen-Gewerkschaft in Freiland (Niederösterreich)	1 778
Ybbstaler Steinkohlenwerke de Majo Ges.m.b.H. in Wien (Bergbaue Gaming und Lunz)	6 301
Übrige Bergbaue	205
B. Braunkohle.	
Revier St. Pölten:	
Statzendorfer Kohlenwerk "Zieglerschächte" A.G. in Wien (Bergbau Statzendorf)	90 380
Berndorfer Metallwarenfabrik Artur Krupp A.G. in Berndorf (Niederösterreich), Bergbau Grillenberg	42 757
Revier Wiener Neustadt:	
Harter Kohlenwerke A.G. in Wien (Bergbau Hart bei Gloggnitz)	55 555
Revier Wels (Oberösterreich):	
Wolfsegg-Traunthaler Kohlenwerks-A.G. in Linz a.D. (Bergbaue Wolfsegg und Thomasroith)	528 712
Elektrizitätswerke Stern u. Hafferl A.G. in Gmunden (Oberösterreich), Bergbau Feitzing	5 004
Übrige Bergbaue	3 543
Revier Leoben (Steiermark):	
Oesterreichisch-Alpine Montan-Gesellschaft in Wien (Glanzkohlenbergbau Seegraben)	314 497
Oesterreichisch-Alpine Montangesellschaft (Glanzkohlenbergbau Fohnsdorf)	427 084
Göriacher Kohlenwerk der Gebr. Böhler & Co. A.G. in Wien (Bergbau Göriach)	52 757
Steirische Kohlenbergwerks A.G. in Wien (Bergbau Parschlug)	34 773
Übrige Bergbaue	40
Revier Graz (Steiermark):	
Oesterreichisch-Alpine Montangesellschaft (Lignitbergbau Köflach)	200 311
Graz-Köflacher Eisenbahn- und Bergbau-Gesellschaft in Graz (Bergbau Zangtal)	56 668
Graz-Köflacher Eisenbahn- und Bergbau-Gesellschaft (Bergbau Oberdorf)	29 246
Graz-Köflacher Eisenbahn- und Bergbau-Gesellschaft (Glanzkohlenbergbaue Kalkgrub-Steyeregg)	70 017
Graz-Köflacher Eisenbahn- und Bergbau-Gesellschaft (Bergbau Rosental)	177 912
Graz-Köflacher Eisenbahn- und Bergbau-Gesellschaft (Lignitbergbau Köflach)	559
Steirische Montanwerke von Franz Mayr-Melnhof in Leoben (Steiermark), Bergbaue Piberstein-Lankowitz	188 331
Steirische Kohlenbergwerks-A.G. in Wien (Bergbau Marienschacht)	52 085
Bergbau Piber III, Felix Holzner in Graz	21 450
Bergbau Friedhofspfeiler der Stadtgemeinde Voitsberg (Steiermark)	8 749
Bergbau Gaiseregg der Brüder Schelch in Gaiseregg	9 384
Ilzer Kohlenwerke Lenz & Co. in Ilz (Steiermark)	4 253
Feistritztaler Bergbau- und Industrie A.G. in Ratten (Oststeiermark), Bergbau St. Kathrein am Hauenstein	47 072
Übrige Bergbaue	5 013

	Produktion.
Revier Klagenfurt (Kärnten):	
Grafen Henckel-Donnersmarck in St. Stefan im Lavanttale (Kärnten), Bergbau St. Stefan	99 530
Kohlenwerk Sonnberg der Oesterreichisch-Amerikanischen Magnesit A.G. in Radenthein (Kärnten)	17 420
Übrige Bergbaue	2 825
Rivier Hall (Tirol):	
Bundesmontanverwaltung Kirchbichl (Kohlenbergbau Häring)	35 550
Revier Wiener Neustadt (Burgenländischer Bergbau):	
Braunkohlenbergbau-Gewerkschaft Zillingdorf in Wien ...	461 515
Schlainінger Bergbau A.G. in Bad Tatzmannsdorf (Burgenland), Bergbau Tauchen	21 076

Wenn es dem österreichischen Kohlenbergbau bisher nicht möglich war, sich einen grösseren Anteil am Gesamtverbrauche sicherzustellen, so liegt dies einerseits in dem reichlichen Angebot an Auslandskohlen am österreichischen Markte, beziehungsweise den sehr niedrigen Preisen der mächtigen Auslandskonkurrenz, anderseits aber—wie bereits erwähnt– an dem Konservatismus der Verbraucher, die im grossen ganzen bei ihren früheren Bezugsquellen verblieben sind, ohne zu beachten, dass sie dadurch die österreichische Wirtschaft sehr schädigen. Es sind zwar in dieser Richtung bereits ansehnliche Erfolge erzielt worden, so dass es immerhin schon möglich war, die Förderung der Kohlenbergbaue über das Vorkriegsniveau auszudehnen. Dieser Erfolg könnte aber zweifellos ein viel grösserer sein, wenn es gelänge, die Verbraucher davon zu überzeugen, dass mit Braunkohle ebenso rationell geheizt werden kann wie mit hochwertiger Steinkohle, wie ja die Beispiele in den Braunkohlenländern zur Genüge beweisen. Leider konnten sich trotz aller Vorstellungen auch die massgebenden Kreise bisher nicht entschliessen, irgend welche *Schutzmassnahmen* zu Gunsten des heimischen Kohlenbergbaues durchzuführen. Während Jugoslawien einen hohen Kohlenzoll eingeführt hat und überdies die eigenen Produzenten (ebenso wie Ungarn) dadurch fördert, dass die Bahnen sehr niedrige Exporttarife (bei sehr hohen Importfrachten) gewähren und in anderen Staaten sogar Kohleneinfuhrverbote nach wie vor bestehen und strenge gehandhabt werden, steht es in Oesterreich jedermann frei, Kohle in beliebigen Mengen einzuführen. Dies geht sogar soweit, dass selbst zahlreiche *staatliche* Anstalten bisher nicht dazu gebracht werden konnten, Inlandskohle zu verwenden, obgleich dies insbesondere anlässlich der Neuerrichtung oder des Umbaues von Feuerungsanlagen sicher möglich gewesen wäre. Man beruft sich namentlich in den Verbraucherkreisen in Bezug auf die Raumheizung auf die nicht bestreitbare Tatsache, dass die Steinkohlenheizung in mancher

Beziehung bequemer sei, dass sich die unmodernen Oefen nicht recht zur Braunkohlenfeuerung eignen etc. Bei gutem Willen und entsprechenden Oefen und Feuerungsanlagen ist die österreichische Braunkohle auch ohneweiteres zur Raumbeheizung gut verwendbar, wie ja das Beispiel Steiermarks und Oberösterreichs zeigt.

Eine wesentliche Ausdehnung der österreichischen Kohlenproduktion wird aber erst möglich sein, wenn sich auch in Oesterreich die Erkenntnis allgemein durchgesetzt hat, dass ein Land in erster Linie d i e Kohle verwenden muss, die es besitzt. Da die österreichische Braunkohle qualitativ weit besser ist als die deutschen Braunkohlen, deren Produktion in den letzten Jahren eine enorme Erweiterung erfahren hat, und ausserdem die Verbraucher in Oesterreich (infolge der Verschiedenartigkeit der Vorkommen) fast jede Kohle erhalten können, die sie für ihre Zwecke benötigen, so ist wohl die Hoffnung berechtigt, dass in den nächsten Jahren der Absatz österreichischer Kohlen eine weitere Ausdehnung erfahren wird. Dies wäre auch im Interesse der Allgemeinheit sehr zu wünschen, denn das kleine und arme Oesterreich kann sich wohl dauernd nicht den *Luxus* gestatten, für jede Art von Verwendungszwecken "Salonkohlen" zu importieren.

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RÉSUMÉ

(SPECIALLY PREPARED)

Austria to-day possesses comparatively few of the coalfields which previously belonged to the Austrian Empire, and as the home production is quite inadequate and consists principally of brown coal, large quantities of hard coal are imported. Special coals, such as gas coal, are not found in Austria, and neither blast furnace coke nor briquettes are manufactured at the present time.

The Austrian market is supplied by most of the larger foreign coalfields. Upper Silesian coal, principally used for household purposes, represents the bulk of imported coal. Czechoslovakia and Germany follow as the next

largest suppliers, while smaller quantities of hard and brown coal are imported from the Saar fields, Holland, England, Hungary and Jugoslavia.

The amounts of Austrian and imported coal consumed during the last six years can be gathered from the detailed figures given.

Coal exports are quite unimportant at present. Viennese gas coke is exported to Hungary, Jugoslavia, Germany, and, in a lesser degree, to Italy, Switzerland, and Bulgaria.

Exports could be considerably increased if those neighbouring countries who produce little or no coal themselves would abolish import duties on coal. Styrian brown coal would be primarily considered for the export trade.

Tables are given showing the quantities of various sorts of coal placed on the Austrian market by foreign coalfields.

Large consumers tend to cling to their old suppliers, and small progress is made in the conversion from hard to brown coal burning.

Viennese industrial consumers still prefer foreign hard coal, and, with the exception of Styria and Upper Austria, Silesian coal dominates the household market.

The calorific value of Austrian bright coal is up to 5,600 cal.; that of brown coal 4,000 to 5,000 cal.; Köflacher lignites have for some time been improved by the Fleissner drying process. This coal, of about 5,300 cal., is a very good substitute for foreign hard coal. In this instance, as well, intensive propaganda is required to create a demand. Difficulties are also experienced in marketing Lunzer furnace coal and Grünbacher hard coal, as the Austrian market has always been held securely by the Rossitzer furnace coal, and the Grünbacher hard coal must compete with the large Polish-Upper Silesian concerns.

The official figures for 1926 give details of Austrian and foreign coals consumed by various industrial consumers.

Coal imports for 1926 exceeded exports to the value of 196,896,000 Austrian shillings, or nearly one-fifth of the adverse balance of all imports and exports for the year. Brown coal still figures prominently in imports, though the Austrian could easily replace the foreign coal.

The Austrian mining industry controls coalfields of about 700 million metric tons. The present output of 3,000,000 metric tons a year could be increased without difficulty to from 4 to 5 million metric tons if a stable demand were forthcoming.

Protection will be necessary to enable remotely situated mines in Styria and Upper Austria to compete with the foreign concerns.

From the tabulated details of Austria's coal production, the mines in operation, labour employed, and the value of the output for 1913, and 1917-1927, it will be seen that the industry is principally in the hands of a few large concerns, such as Grünbacher Steinkohlenwerke A.G. in Lower Austria; Wolfsegg-Traunthaler Kohlenwerke A.G. in Upper Austria; Oesterreichisch-Alpine Montangesellschaft and the Graz-Köflacher Eisenbahn und Bergbau Gesellschaft, both in Styria; Steirische Montanwerke von Fr. Mayr-Melnhof, in Styria; Braunkohlenbergbau-Gewerkschaft in Zillingdorf.

The absence of a syndicate increases the difficulties of the situation. Continued attempts to form a combine have been made during the last few years, but the scattered position of the mines and dissimilarity of the coal produced are the main reasons for the failure of these attempts.

From the facts enumerated above, it will be seen that the principal factors responsible for keeping Austrian coal out of the home market are the large quantities of cheap foreign coal imported and the conservative attitude adopted by the consumers, who cling to their former suppliers with no regard to the detrimental economic effect on the home industry. Some success in this direction must be admitted, but this could be considerably increased if consumers could be persuaded that brown coal will burn as economically as hard coal.

Unfortunately, no move has been made as yet in official circles to introduce some protection for the coal industry. Jugoslavia, for instance, not only levies a high import duty on coal, but assists the home industry further by low export and high import freight charges. Even Austrian Government departments have not so far been persuaded to patronise the home industry.

Consumers argue that the old type stoves are not suitable for use with brown coal. But with a little goodwill and the modification of stoves, Austrian brown coal is quite an efficient fuel, as the example set by Styria and Upper Austria proves.

A noticeable improvement in Austrian coal production will only become a possibility when it is generally realised that a country must first and foremost make use of the coal it possesses, and as the quality of Austrian brown coal is stated to be superior to that of the German brown coal, a better and increasing demand for home produced coal is hoped for in the next few years.

VORSCHLAG ZUR BRENNSTOFFTECHNISCHEN KENNZEICHNUNG DER KOHLEN

(PROPOSALS FOR TECHNICAL DESIGNATIONS OF COAL CHARACTERISTICS)

GESELLSCHAFT FÜR WÄRMEWIRTSCHAFT, WIEN

Paper No. A4

CONTENTS

TECHNICAL DESIGNATIONS IN USE—THEIR DEFICIENCIES—PROPOSED COAL SURVEY RECORDS—EXAMPLES OF THEIR APPLICATION IN AUSTRIA
RÉSUMÉ

In der industriellen Praxis kommt der Kohlenverbraucher häufig in die Lage, sich über die Eigenschaften bestimmter Kohlen vor ihrer laboratoriumsmässigen Untersuchung bezw. betriebsmässigen Erprobung in brennstofftechnischer Hinsicht eine Vorstellung machen zu sollen. Da die vom Kohlenlieferanten allenfalls mitgeteilten Angaben (Heizwertziffern, Analysendaten) in der Regel keinen integrierenden Bestandteil des Kohlenangebotes bezw. Lieferungsübereinkommens bilden, so ist der Verbraucher meist bestrebt, auch aus anderen Quellen Untersuchungsdaten über die fraglichen Kohlen zu erhalten, welche ihm Anhaltspunkte in der genannten Hinsicht bieten sollen.

Nicht selten ist der Kohlenverbraucher hiebei geneigt, in der ihm gebotenen Heizwertziffer einen absoluten Masstab für den Wert der betreffenden Kohle zu erblicken, ohne zu beachten, dass die Verwendbarkeit der Kohlen auch von anderen Eigenschaften beeinflusst wird, dass aber namentlich der Heizwert von Kohle Schwankungen unterliegt, welche von mannigfachen Verhältnissen abhängen. Eben diese Schwankungen sind es jedoch, welche der Orientierung an Hand willkürlich herangezogener Daten nur einen sehr zweifelhaften Wert zukommen lassen bezw. eine tatsächliche Orientierung, welche letzten Endes die Durchschnittseigenschaften der Kohle erfassen soll, sehr erschweren.

Es ist daher der Gedanke naheliegend, eine Datensammlung für Orientierungszwecke, einen "Kohlenkataster," zu schaffen, welcher dem Verbraucher Aufschluss über die Durchschnittseigenschaften der einzelnen Kohlen geben soll. Aber auch solchen Bestrebungen stellen sich bei näherer Betrachtung Schwierigkeiten entgegen, da die Durchschnittseigenschaften der einzelnen Kohlenvorkommen in unbedingt exakter Weise nicht erfassbar sind. Der dadurch bedingte Verzicht auf exakte Durchschnittswerte schliesst jedoch die Ermittlung von Näherungswerten nicht aus, welche als *Anhaltswerte* in der Praxis gute Dienste leisten können.

Von dieser Erwägung geleitet, hat es die Gesellschaft für Wärmewirtschaft unternommen, zur Aufstellung eines "Kohlenkataster" eine Sammlung von Orientierungsdaten für die Kohlen des österreichischen Marktes einzuleiten, welche sich zunächst auf die *wichtigsten Kohlenvorkommen in Oesterreich* bezieht. Hiebei waren folgende Gesichtspunkte massgebend:

Die Analysenwerte von Kohlen schwanken, vornehmlich beeinflusst durch den jeweiligen Asche- und Wassergehalt, um Mittelwerte. Die Analyse einer einzelnen Probe kann im allgemeinen nur ein Zufallsergebnis liefern, welches beispielsweise für den Tag der Probenahme Geltung haben kann. Derartige Analysenwerte stellen jedenfalls keinen Durchschnitt dar und können daher nur in beschränktem Ausmasse zur Charakteristik des Kohlenvorkommens dienen. Dagegen ist bekannt, dass die *chemische Zusammensetzung der Reinkohle* (aschen- und wasserfreie Kohle, brennbare Substanz) *und ihr Heizwert* in Bezug auf den Durchschnitt des Flözquerschnittes *fast unveränderlich* sind.

Für die Ermittlung der Anhaltswerte des "Kohlenkatasters" wurde daher durch folgendes Verfahren eine Annäherung an Durchschnittsverhältnisse angestrebt.

Es wurde eine möglichst grosse Zahl von Analysen- und Heizwertdaten einer Kohle (Grube) sowohl durch Werksangaben als auch aus der Literatur gesammelt, aus diesen Analysenwerten die Zusammensetzung der Reinkohle berechnet und mit Hilfe des in diesen Analysen angegebenen Heizwerten der *Reinkohlenheizwert* ermittelt.

Hiefür bestehen folgende Beziehungen:

$$H_u = \frac{100 - a - w}{100} \times H_{uR} - 6w^* \ldots\ldots\ldots\ldots (1)$$

*Die Verdampfungswärme des Wassers wurde mit 640 kcal in den Berechnungen eingesetzt. Die sich daraus ergebenden Abweichungen gegenüber der meist üblichen Verwendung des Wertes von 600 sind geringfügig.

und daher

$$H_{uR} = (H_u + 6w^*) \times \frac{100}{100-a-w} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

ferner gilt bezgl. der chemischen Zusammensetzung der Reinkohle:

$$\text{Kohlenstoff: } C_1 = \frac{100}{100-a-w} \cdot C$$

$$\text{Wasserstoff: } H_1 = \frac{100}{100-a-w} \cdot H$$

u.s.w.

Hiebei bedeutet:

H_{uR} = unterer Heizwert der Reinkohle.
H_u = unterer Heizwert der Rohkohle.
a = Aschegehalt in % der Rohkohle.
w = Wassergehalt in % der Rohkohle.
C_1 = Kohlenstoffgehalt in % der Reinkohle.
H_1 = Wasserstoffgehalt in % der Reinkohle.
C = Kohlenstoffgehalt in % der Rohkohle.
H = Wasserstoffgehalt in % der Rohkohle.

Nach Berechnung der Zusammensetzung und des Heizwertes der Reinkohle aus jeder einzelnen Analyse, wurden die offensichtlich zu hohen oder zu tiefen Werte (diejenigen, welche um mehr als 200 kcal/kg bezüglich des Reinkohlenheizwertes voneinander abwichen) ausgeschieden und aus den restlichen Werten, welche innerhalb des genannten Streuungsbereiches lagen, das arithmetische Mittel gezogen. Von den so erhaltenen Werten ist wohl mit Recht anzunehmen, dass sie den idealen Durchschnitten der Reinkohlenheizwerte nahekommen, jedenfalls aber als *ernste Anhaltswerte* hiefür gelten können. Bezüglich der chemischen Zusammensetzung der Reinkohle wurde grundsätzlich der gleiche Vorgang eingehalten; die geringfügigen Differenzen, um welche die Summen der Perzentziffern jeweils von 100 abwichen, wurden durch Ab- bezw. Aufrundung ausgeglichen. Die so gefundene Zusammensetzung der Reinkohle wurde für die betreffende Kohle als *charakteristisch* angenommen. Der Gehalt der Reinkohle an flüchtigen Bestandteilen wurde auf Grund vorhandener Analysendaten in gleicher Weise ermittelt. (Bei der bisher durchgeführten Datensammlung musste ein Teil dieser Werte mangels genügender Unterlagen geschätzt werden.)

*Die Verdampfungswärme des Wassers wurde mit 640 kcal in den Berechnungen eingesetzt. Die sich daraus ergebenden Abweichungen gegenüber der meist üblichen Verwendung des Wertes von 600 sind geringfügig.

Auf Grund der vorliegenden Analysen der einzelnen Kornklassen (Sortierungen) wurde deren wahrscheinlichster Wasser- und Aschegehalt als arithmetisches Mittel errechnet, (wieder unter Ausschaltung aller jener Werte, welche zu weit vom Häufigkeitsmaximum entfernt lagen) bezw. geschätzt. Diese Wasser- und Aschegehaltsziffern wurden für die betreffende Kornklasse als kennzeichnend angenommen. Die chemische Zusammensetzung der Rohkohle in Bezug auf die einzelnen Kornklassen wurde mit Hilfe der früher angeführten Gleichungen rückgerechnet, woraus sich die Zahlenwerte ergaben, welche zur Aufstellung der Rohkohlendaten des "Kohlenkatasters" benützt wurden. Die errechneten Zahlenwerte wurden auf die erste Dezimale gekürzt, von der Ueberlegung ausgehend, dass Schwankungen im Asche- und Wassergehalt von mehreren Prozenten, je nach den jeweiligen Grubenverhältnissen möglich sind, weshalb eine grössere Genauigkeit der Zahlenangaben irreführend wäre. Die Heizwertziffern wurden im gleichen Zusammenhange auf 10 ab- bezw. aufgerundet.

Alle ermittelten Rohkohlenzahlenwerte beziehen sich auf die Brennstoffe an der Grube; dieser Hinweis ist namentlich bei Brennstoffen mit höherem Wassergehalt wichtig, da beim Transport eine Abtrocknung eintritt. Er ist insbesondere dann zu beachten, wenn verschiedene Kohlen mit starken Abweichungen des Wassergehaltes verglichen werden sollen.

Bezüglich des "Kataster"- Kopfes wird bemerkt, dass seine bisherige Ausgestaltung nicht nur von Zweckmässigkeitserwägungen sondern auch von der tatsächlichen Verfügbarkeit einzelner Datenkategorien massgebend beeinflusst wurde. Bezüglich der Rohkohlendaten ist hervorzuheben, dass ihnen ein wesentlich unverbindlicherer Charakter zukommt als den Reinkohlendaten. Der Wortlaut des Katasterkopfes: "Einem Gehalt an Wasser (.....) und Asche (.....) *entsprechen* in der Rohkohle (.....)" soll diesem Umstand Rechnung tragen.

Der bisher entworfene "Kohlenkataster" erstreckt sich vorläufig über fast alle österreichischen Kohlenbergbaue, welche im Jahr 1926 mehr als 5000 Tonnen Jahresförderung aufwiesen. Eine gleichartige Bearbeitung der für den österreichischen Markt wichtigen Auslandskohlen ist anschliessend in Aussicht genommen. Eine Aufgabe der weiteren Bearbeitung des "Kohlenkatasters" soll ferner darin bestehen, durch fortlaufende Sammlung von Kohlendaten allfällige wesentliche zeitliche Veränderungen in den Eigenschaften der einzelnen Kohlenvorkommen, Veränderungen der

Sortierungen, u.s.w. zu erfassen. Auch bei restloser Erreichung dieses Zieles soll der "Kohlenkataster" jedoch stets den Charakter eines Orientierungsbehelfes wahren, der die für viele praktische Zwecke erforderliche Kohlenuntersuchung an Hand bestimmter Proben, bezw. die praktische Erprobung einer Kohle im Betrieb nicht ersetzen kann.

Das Verlangen fortschrittlich eingestellter Kohleninteressenten nach solchen Orientierungsdaten wird namentlich derjenige begreiflich finden, dem bekannt ist, wie häufig die verschiedensten Veröffentlichungen über Heizwertuntersuchungen (Sammelberichte von Laboratorien, Bücher über Kohlenkunde, einschlägige Aufsätze in Zeitschriften u.s.w.), welche nur die Ergebnisse der Untersuchung einzelner Proben, d.h. günstige oder ungünstige Zufallswerte enthalten, wahl- und bedenkenlos zur Kohlenbeurteilung verwendet werden und welche Unzukömmlichkeiten sich daraus ergeben können.

Der besondere Charakter der auf die beschriebene Weise ermittelten Orientierungsdaten lässt es jedoch notwendig erscheinen, bei vergleichsweiser Beurteilung mehrerer Kohlenarten auf ausschliessliche Verwendung solcher Orientierungsdaten bedacht zu sein, jedenfalls aber die einseitige Heranziehung anderer, nicht gleichwertig definierter Kohlendaten sorgfältig zu vermeiden, um Trugschlüssen vorzubeugen.

Dieser Umstand lässt es der Gesellschaft für Wärmewirtschaft als angezeigt erscheinen, von den nach dem beschriebenen Verfahren ermittelten Daten über die wichtigsten österreichischen Kohlen vorläufig nur Einzelbeispiele* anzuführen und die Veröffentlichung des Gesamtmaterials erst zu einem späteren Zeitpunkte ins Auge zu fassen, wobei angenommen wird, dass inzwischen die Aufstellung von Kohlenkatastern auch in anderen Ländern verwirklicht wird.

Die Anregung der Gesellschaft für Wärmewirtschaft an die Fuel Conference geht dahin, die Nationalkomitees einzuladen, auch in ihren Ländern die Einleitung gleichgerichteter Arbeiten zu erwägen. Die Gesellschaft für Wärmewirtschaft stellt insbesondere das Verfahren, welches zur Ermittlung von brennstofftechnischen Orientierungsdaten über Kohlen verwendet werden soll, zur Diskussion und würde es lebhaft begrüssen, wenn ihr Vorschlag zu einer internationalen Bearbeitung dieses Gegenstandes und zur Festlegung einer einheitlichen Methode der "Kohlenkataster"-Aufstellung führen würde.

*Siehe Anhang.

TABELLENBEISPIEL AUS DEM BISHER BEARBEITETEN KOHLENKATASTER.
(1) KOHLE VON GRÜNBACH.

Art und Herkunft	Revier	Bergbau Besitzer Jährl. Förd. 1926 Bahnstation	Aussehen	Reinkohle C	H	O+N	Sv	Ho	Hu	Fl
Steinkohle Kreide	St. Pölten	Grünbach Grünb. Steinkohlenwerke A.G. 128 933 t Grünbach-Klaus	Schwarz, schwach glänzend bis glänzend, schieferig/muschelig	76,4	5,5	16,7	1,4	7520	7200	42,0

Rohkohle

Sorte	Korngrösse mm	Einem Gehalt an Wasser %	Asche %	entsprechen in der Rohkohle C%	H%	O+N%	Sv%	Ho	Hu	Fl%
Stück ..	über 60	5,0	5,0	68,7	5,0	15,0	1,3	6770	6450	37,8
Würfel ..	30/60	5,5	5,1	68,3	4,9	14,9	1,3	6720	6400	37,6
Nuss ..	15/30	5,5	15,0	60,7	4,4	13,3	1,1	5990	5690	33,4
Erbs ..	5/15	5,5	18,5	58,0	4,2	12,7	1,1	5720	5440	31,9
Staub ..	0/5	6,0	18,5	57,6	4,2	12,6	1,1	5680	5400	31,7

C Kohlenstoff.
H Wasserstoff.
O+N Sauerstoff u. Stickstoff.
Sv verbrennlicher Schwefel.
Ho oberer Heizwert (Verbrennungswärme).
Hu unterer Heizwert.
Fl Flüchtige Bestandteile.

TABELLENBEISPIEL AUS DEM BISHER BEARBEITETEN KOHLENKATASTER.
(2) KOHLE VON SEEGRABEN.

Art und Herkunft	Revier	Bergbau Besitzer Jährl. Förd. 1926 Bahnstation	Aussehen	Reinkohle C	H	O+N	Sv	Ho	Hu	Fl
Braunkohle miozän inneralpin	Leoben	Seegraben Oest. Alp. Montangesellschaft 296 143 t Leoben	Grauschwarz bis schwarz, schwarz- bis starkglänzend, muschelig	73,0	5,4	20,9	0,7	7260	6950	39

Rohkohle

Sorte	Korngrösse mm	Einem Gehalt an Wasser %	Asche %	entsprechen in der Rohkohle C%	H%	O+N%	Sv%	Ho	Hu	Fl%
Stück ..	über 80	8,6	8,5	60,5	4,5	17,3	0,6	6010	5700	32,3
Würfel ..	40/80	9,5	9,1	59,4	4,4	17,0	0,6	5910	5590	31,7
Nuss gew.	15/40	10,0	9,9	58,5	4,3	16,7	0,6	5820	5500	31,2
Gries ,,	7/15	11,5	10,1	57,2	4,2	16,4	0,6	5690	5370	30,6
Gries ungew. ..	7/15	9,0	16,0	54,8	4,0	15,7	0,5	5450	5160	29,3
Staub ..	0/7	9,0	19,0	52,6	3,9	15,0	0,5	5340	4940	28,1

C Kohlenstoff.
H Wasserstoff.
O+N Sauerstoff u. Stickstoff.
Sv verbrennlicher Schwefel.
Ho oberer Heizwert (Verbrennungswärme).
Hu unterer Heizwert.
Fl Flüchtige Bestandteile.

TABELLENBEISPIEL AUS DEM BISHER BEARBEITETEN KOHLENKATASTER

(3) KOHLE VON KÖFLACH (Karlsschacht, Grubenfeuchte Kohle).

Art und Herkunft	Revier	Bergbau Besitzer Jährl. Förd. 1926 Bahnstation	Aussehen	Reinkohle						
				C	H	O + N	Sv	Ho	Hu	Fl
Braunkohle miozän voralpin	Graz	Karlsschacht Oest. Alp. Montangesellschaft 163 378 t Oberdorf	Graubraun, matt schieferig-erdig.	69,3	5,4	25,0	0,3	6760	6450	52,8

Rohkohle

Sorte	Korngrösse mm	Einem Gehalt an		entsprechen in der Rohkohle						
		Wasser %	Asche %	C%	H%	O + N%	Sv%	Ho	Hu	Fl
Stück ..	über 110	34,5	6,5	40,8	3,2	14,8	0,2	3990	3590	31,2
Mittel ..	40/110	34,5	6,5	40,8	3,2	14,8	0,2	3990	3590	31,2
Nuss ..	20/40	36,5	9,0	38,2	2,3	13,8	0,2	3720	3320	29,1
Grobgries	8/20	36,0	11,0	36,7	2,9	13,2	0,2	3580	3190	28,0
Staub ..	0/8	36,4	18,0	31,6	2,5	11,4	0,1	3080	2710	23,1

C Kohlenstoff.
H Wasserstoff.
O + N Sauerstoff u. Stickstoff.
Sv verbrennlicher Schwefel.
Ho oberer Heizwert (Verbrennungswärme).
Hu unterer Heizwert.
Fl Flüchtige Bestandteile.

TABELLENBEISPIEL AUS DEM BISHER BEARBEITETEN KOHLENKATASTER.

(4) KOHLE VON KÖFLACH (Karlsschacht, nach dem Verfahren von Professor Dr. Fleissner getrocknete Kohle).

Allgemeine Daten wie auf Tabellenblatt (3).

Rohkohle

Sorte	Korngrösse mm	Einem Gehalt an		entsprechen in der Rohkohle						
		Wasser %	Asche %	C%	H%	O + N%	Sv%	Ho	Hu	Fl
Stück ..	über 90	16,5	8,7	51,9	4,0	18,7	0,2	5060	4720	39,5
Mittel ..	35/90	16,0	8,9	52,0	4,1	18,8	0,2	5080	4740	39,7
Nuss ..	15/35	15,0	12,0	50,6	3,9	18,3	0,2	4930	4610	38,5
Grobgries .	10/15	14,0	14,7	49,4	3,9	17,8	0,2	4820	4510	37,7
Feingries ..	4/10	13,5	18,0	47,5	3,7	17,1	0,2	4720	4420	36,2
Staub ..	0/4	12,0	23,0	45,0	3,5	16,3	0,2	4400	4120	34,4

C Kohlenstoff.
H Wasserstoff.
O + N Sauerstoff u. Stickstoff.
Sv verbrennlicher Schwefel.
Ho oberer Heizwert.
Hu unterer Heizwert.
Fl Flüchtige Bestandteile.

RÉSUMÉ

In many instances it is necessary for industrial consumers to form an opinion of the quality and nature of certain coals, before they can be fully tested by them. The suppliers' information is not always satisfactory and confirmatory data is looked for in other directions. The consumer tends to regard the information on the calorific value obtained in this way, as a positive guide to the coal value, whereas the calorific value is governed by varying conditions and fluctuates considerably. Suggestions have been made for the preparation of reference tables, giving an average of all data available for the various

coals on the market. The "Society for Fuel Economy," Vienna, is engaged in the preparation of such averages; at present only the larger Austrian mines have been considered, but reference tables for the foreign coals on the Austrian market will eventually be prepared.

It is generally known that the chemical composition and the calorific value of pure coal (ash and moisture free), remains almost constant throughout the section of a seam. To obtain these reference values, as many reports as possible on the calorific value and analysis of the coal from a particular mine were collected; the composition and calorific value of the pure coal was then determined for each report. After eliminating those values, obviously too high or too low, the average figures were obtained. All data referring to ordinary coal were calculated under pit-head conditions, as during transit a certain amount of evaporation takes place. It is intended to keep the reference tables up-to-date, by continual revisions, when more data is available, and when changes in the peculiarities of any particular coal or alteration of sorting methods take place. It is claimed that these reference figures approach as near as possible the ideal average of pure coal values. At the same time, they are only a guide and cannot take the place of chemical analysis or practical tests.

The "Society for Fuel Economy," in submitting these proposals to the World Power Conference, recommends the introduction of similar methods in other countries, and would regard an international agreement and adoption of standard methods with favour.

A STUDY OF POST-CARBONIFEROUS COALS

SCIENTIFIC AND INDUSTRIAL RESEARCH COUNCIL OF ALBERTA

DR. EDGAR STANSFIELD

Paper No. A5

CONTENTS

RESERVES AND PRODUCTION—CLASSIFICATION OF POST-CARBONIFEROUS COALS—INFLUENCE OF GEOLOGICAL AGENCIES—PROGRESSIVE METAMORPHISM—THE ANALYSIS OF HIGH-MOISTURE COALS—GENERAL CLASSIFICATION OF COALS—UTILISATION—RÉSUMÉ

The earlier known and more important coalfields of Europe, and of eastern North America, are of Carboniferous age. It is quite natural, therefore, that early work was almost entirely confined to such coal; and methods of analysis and systems of classification were adapted to this coal. Even now, comparatively little study has been made of Post-Carboniferous coals. This neglect is certainly not justified in view of the extent of the world's reserves of the latter, and is only partly justified by the comparatively small annual production of such coals.

Reserves and Production

Approximately 68 per cent. of all the estimated coal reserves in the United States are Post-Carboniferous, if it is assumed that the lignite deposits of Texas and Arkansas and all coal deposits west of the 100th meridian belong to that age.[1] In Canada, only the deposits of Nova Scotia, New Brunswick and the Arctic Islands are Carboniferous, and over 98 per cent. of all the estimated coal reserves are Post-Carboniferous.[2] The coal of Mexico is also Post-Carboniferous. According to the International Geological Congress (1913) the United States and Canada possess nearly 52 per cent. and nearly 17 per cent., respectively, of the total coal reserves of the

[1] *Our Coal Supply; Its Quantity, Quality and Distribution.* By M. R. Campbell, Pittsburgh International Conference on Bituminous Coal, 1926.

[2] *Coal Resources of the World.* International Geological Congress, 1913.

world, so that the Post-Carboniferous deposits of North America alone account for over 50 per cent. of the total deposits of the world. The respective figures for production are materially different. In the United States 5 or 6 per cent. only of the total production up to the end of 1925 was of the more recent coal, and the same limits of 5 to 6 per cent. would cover the annual production as recently as 1923. In Canada the annual production of Post-Carboniferous coals was 60 per cent. of the whole in 1923, and 53 per cent. of the whole in 1927. As the United States production in 1923 was about 44 per cent. of the total production of the world, Canada's production slightly over 1 per cent., and Mexico's production less than 0·1 per cent., the total production of Post-Carboniferous coals in North America only amounted to 3 per cent. of the world production in that year. North America, therefore, does not figure as prominently as a producer of Post-Carboniferous coals as it does in respect to reserves of such coal. In 1923 Germany produced over 118,000,000 tons (2,000 lb.) of lignite, which amounted to nearly 9 per cent. of the total world production of coal, and in many other countries large quantities of the more recent coals are mined, so that the annual world's production of such coals is far from negligible.

Classification of Post-Carboniferous Coals

It is sometimes assumed that coals of the more recent geological age are mainly lignitic in character, and Carboniferous coals are referred to as *true* coals. It may be correct that Tertiary coals are mainly lignitic, but this is certainly far from true of the Cretaceous coals. In a recently estimated "original tonnage" of coal in the United States, the coals west of the 100th meridian, together with the lignite deposits of Texas and Arkansas, aggregated 2,354,235,000,000 tons (2,000 lb.). Of this amount only 39·9 per cent. was classed as lignite, 42·3 per cent. as sub-bituminous, 17·8 per cent. as bituminous, and a trifling percentage as anthracitic. The Post-Carboniferous coals of Canada, according to the International Congress of Geology, 1913, consist of nearly 78 per cent. lignite, nearly 22 per cent. bituminous, and one-third of one per cent. anthracitic and cannel coals. A more recent estimate of available coal supply in Alberta[3] gave 18 per cent. only as "Alberta lignite," 23 per cent. as sub-bituminous and 59 per cent. as bituminous coal. Unfortunately the classification of coals employed is different in each of the three sets of statistics quoted above.

[3] Dr. J. A. Allan, Scientific and Industrial Research Council of Alberta, Annual Report for 1925, p. 43.

In a recent paper by Dr. Marius R. Campbell,[4] which has been freely consulted for the statistics and analyses of United States coals included in this paper, nine ranks of coal are shown, intermediate between peat and a substance he calls super-anthracite. The ranks named are peat, lignite, sub-bituminous, low-rank bituminous, medium-rank bituminous, high-rank bituminous, low-rank semi-bituminous, high-rank semi-bituminous, semi-anthracite, anthracite and super-anthracite. In this classification cannel coals are included in the bituminous ranks. The classification officially employed in Alberta includes only three ranks—bituminous, sub-bituminous, and domestic. (No anthracite is being mined at present.) If Dr. Campbell's classification were employed it is clear that most of Alberta's sub-bituminous coal would be classed as low-rank bituminous, and most of its domestic coal as sub-bituminous. The only mines producing lignite, according to this classification, would be some small mines situated on the eastern border of the coalfields, which produce coal for local use only. The present production of British Columbia is about 95 per cent. bituminous, and of Saskatchewan entirely lignite, so that just at present problems of classification are less important in those provinces than in Alberta. The classification employed in the statistics of the coal resources of the world are fully stated, although not easy to interpret, but here again it is certain that the percentage of lignite coal reported in Canada would have been materially reduced if Dr. Campbell's classification had been employed. The need for a uniform system of classification is quite evident, and this subject will be more fully discussed later.

Influence of Geological Agencies

It is safe to assume that, other things being equal, a Carboniferous coal is always of higher rank than a Post-Carboniferous coal. In other words, a comparatively undisturbed seam of Carboniferous coal, by mere passage of time and the pressure from superincumbent strata, has become more metamorphosed from the original vegetal matter than has an equally undisturbed seam of Post-Carboniferous coal, with its shorter time since deposition, and probably smaller pressure from superincumbent strata. This can also be expressed by saying that of two coals of equal rank but of unequal geological age, the newer coal must have been subjected either to the greater pressure due to the folding of the strata and the uplift of mountains, or to heat due to igneous intrusions or to lava flows.

[4] Pittsburgh International Conference on Bituminous Coal, 1926.

The general character of Post-Carboniferous coals reflects their geological history. The higher rank coals of this age in North America are almost entirely confined to mountainous or hilly country, and no large, flat beds of uniform, higher rank composition are known. The variability of composition can be seen in the three following analyses of coals from adjacent localities in the north-west of the State of Colorado.

TABLE I.
COLORADO COAL ANALYSES.

	Moisture.	Ash.	Volatile matter.	Fixed carbon.	Fuel ratio.
North Park Field	20·0	5·0	32·5	42·5	1·3
Yampa Field ...	10·4	6·2	37·9	45·5	1·2
Yampa Field ...	7·0	14·0	3·4	75·6	22·2

TABLE II.
SOUTHERN ALBERTA COAL ANALYSES.

Sample.	Distance miles.	Moisture per cent.	Ash per cent.	Volatile matter per cent.	Fixed carbon per cent.	Fuel ratio.	Calorific value B.Th.U./lb.
1	8	1·7	10·6	24·5	63·2	2·6	13,490
2	11	1·7	12·5	24·0	61·8	2·6	13,160
3	15	1·3	12·5	27·2	59·0	2·2	13,130
4	22	7·3	13·0	35·2	44·5	1·25	11,630
5	83	10·6	8·3	35·7*	45·4	1·25	11,270
6	115	15·1	10·2	31·4*	43·3	1·40	10,060
7	162	21·8	6·8	29·5*	41·9	1·40	9,190
8	177	26·6	7·8	27·3*	38·3	1·40	8,290

* Volatile matter determined by slow coking.

In British Columbia most of the producing mines are working bituminous coals, but published analyses show coals with fuel ratios varying from less than 1 to over 20. In Alberta the effect of mountain building pressure on the rank of the coal is very clear. The Rocky Mountains were forced up by pressure from the west. The effect of this pressure is naturally most clearly shown within the limits of the mountains, and decreasingly shown with increasing distance east from the mountains. This has been illustrated by means of a map showing the normal moisture content of coal mined in Alberta.[5] The lines of equal moisture content lie approximately

[5] *Analyses of Alberta Coals.* Stansfield, Hollis and Campbell, Report 14, Scientific and Industrial Research Council of Alberta, p. 14.

parallel to the mountains, and the moisture increases with increased distance from the mountains. The same thing is shown by the following analyses of coals taken along the line of the Canadian Pacific Railway from the Crow's Nest Pass through the Rocky Mountains eastwards through Lethbridge to Medicine Hat. Distances are expressed in miles, as the crow flies, from the summit of the pass to the point where the sample was taken. The first three samples came from within the mountain range.

Progressive Metamorphism

All the above coals are of Cretaceous age, the first three from the Kootenay horizon, and the others from the Belly River horizon. Other series of samples, taken at right-angles away from the line of the mountains, show a similar gradual decrease in rank of the coal, even though farther north, along the main line of either the Canadian Pacific Railway or the Canadian National Railway, for example, such a series would pass, geologically, from Kootenay to Belly River, from Belly River to Edmonton and then back to Belly River horizon coals.

Another corollary of the fact that the seams of higher rank Post-Carboniferous coals have commonly been subjected to high pressures and are much faulted and folded is that such coals often have a higher ash content than is found in the lower rank coals. This is probably due to the earth movements causing a mixing of the purer coal with the dirt partings in the seam, so that they cannot be separated when mined. In the hundred typical analyses of Western United States coals quoted by Dr. Campbell in the paper already referred to, forty-seven samples classed as lignite or sub-bituminous show an average ash content of 7·8 per cent., while fifty-three samples classed as bituminous, semi-bituminous, semi-anthracite and anthracite show an average ash content of 10·9 per cent. This increase of ash with increase of rank is a rule with many exceptions, but the same tendency is clearly shown in Alberta coals. The increase of ash content is accompanied by a rise in the softening temperature of the ash.

Where a Carboniferous coal attained a certain rank or maturity by extremely slow metamorphosis, and a Post-Carboniferous coal matured so as to have the same proximate analysis in a geologically shorter time, it is only natural to expect that the two resultant coals, although of the same proximate analysis, will be notably different in other respects. Such possible differences should be considered with respect to methods of analysis, classification and

utilisation of the more recent coals; and further study is desirable along these lines.

The Analysis of High-Moisture Coals

Post-Carboniferous coals are normally analysed by the same methods employed for Carboniferous coals, but the coals with higher moisture content are particularly unstable, and require special precautions to be taken. The pulverised coal oxidises with notable rapidity in such a way as to increase the moisture content, even when the coal is stored in bottles with tightly-fitting glass stoppers. Analyses, therefore, should be carried to completion as soon as possible after grinding. Moisture determinations should be made in an oven through which a rapid stream of a dry, neutral gas is passed, for if air is circulated through the oven, oxidation causes serious errors. Volatile matter determinations must be made by the slow coking method to avoid loss from sparking, where the moisture in the air-dried coal is higher than about 10 per cent. As the moisture-retaining properties of the higher moisture coals give an indication of the nature of such coals, a standardised method of air drying is advisable. In the writer's laboratory the coal is exposed in a shallow tray for forty-eight hours to a rapid current of air of 60 per cent. humidity at room temperatures. The humidity is regulated by exposing the air to a stream of calcium chloride solution of 1·30 specific gravity.

General Classification of Coals

Enough has already been said to show the present need for the general adoption of a scheme of coal classification which will suit both Carboniferous and Post-Carboniferous coals. Representative committees in Canada and the United States are at present working on this problem, and little more need be said about it now. In the writer's opinion no scheme will be entirely satisfactory which does not take cognisance in some way of the normal moisture content of the coal. One example, Table III., has been selected to make this clear. Samples A and B, if judged by the analyses of the dry coals, are not very markedly dissimilar; sample A has the higher calorific value, in spite of a slightly higher ash content, but sample B has the higher fuel ratio. The analyses of the coals moist as mined, however, show the marked superiority of sample A, and this comparison agrees with the ordinary commercial rating of the two coals. Sample A came from the Coalspur area in Alberta, and sample B from Tofield, some 180 miles farther east.

TABLE III.

COMPARISON OF ANALYSES—MOIST AND DRY COALS.

Fuel.	Moisture per cent.	Ash per cent.	Volatile matter per cent.	Fixed carbon per cent.	Fuel Ratio.	Calorific value B.Th.U./lb.
Sample A, dried	—	9·3	39·3	51·4	1·30	12,000
Sample B, dried	—	9·8	37·1	54·1	1·45	11,770
Sample A, as mined	7·7	8·5	36·3	47·5	1·30	11,080
Sample B, as mined	27·8	6·4	26·8	39·0	1·45	8,500

It is of interest to note that a preliminary study of the classification of Alberta coals by Seyler's method, comparing the carbon, hydrogen, and oxygen plus nitrogen content of the dry, pure coal substance, shows these coals to fall principally into the ortho-semibituminous, meta-bituminous, ortho-bituminous, meta-lignitous, ortho-lignitous and sub-ortho-lignitous classes. Some samples have been analysed which fall into the ortho-carbonaceous, sub-meta-bituminous, sub-ortho-bituminous and per-meta-lignitous classes. This indicates the wide range of Post-Carboniferous coals to be found, even within the comparatively small area of Alberta.

Utilisation.

The utilisation of Post-Carboniferous coals does not fall within the scope of this study of their composition and classification, but it might be pointed out that they include coals suitable for making coke and gas, for the production of power, etc., and it is anticipated that some of these coals will be particularly suited for the production of oil by the Bergius process. The higher moisture coals, 10 per cent. and upwards, are clean to handle, and burn with practically no smoke, presumably on account of their high oxygen content, so that they are well adapted for use as domestic fuel.

As these coals are found near the surface in many localities, and under conditions leading to possibilities of cheap mining, their suitability for many of the modern processes of coal treatment will undoubtedly lead to their becoming of far greater economic importance in the near future.

RÉSUMÉ.

Les houilles post-carbonifères, dans la seule Amérique du Nord, représentent plus de la moitié des réserves carbonifères du monde entier. Elles ne représentent, au moment actuel, qu'un faible pourcentage de la production mondiale

annuelle de la houille, mais même au point de vue de la production elles sont loin d'être négligeables.

Les houilles post-carbonifères sont souvent considérées comme étant de nature principalement ligneuse, mais il s'en faut de beaucoup que cela soit vrai. Elles comprennent des quantités importantes de toutes les espèces de houilles, du lignite jusqu'à l'anthracite. L'analyse chimique d'un échantillon d'une certaine catégorie de houille post-carbonifère peut, en effet, bien être la même que celle d'un échantillon de houille carbonifère de la catégorie semblable, mais le caractère général des couches fait voir l'influence qu'exercèrent les forces qui ont formé l'architecture des montagnes sur les métamorphoses progressives de la matière végétale.

Les méthodes d'analyse, la classification et l'utilisation des houilles ont été, dans le passé, largement inventées pour servir aux houilles carbonifères, et il conviendrait de considérer davantage et d'étudier de façon plus approfond les houilles post-carbonifères, tout particulièrement au point de vue de la classification. Il y a besoin pressant d'un système de classification qui se prêtera à toutes les houilles de toutes les époques et qui sera, conséquemment, adopté par consentement général. La nomination récente de commissions représentatives pour préparer cette classification au Canada et aux Etats-Unis constitue un pas de fait dans la bonne direction. Une certaine modification apportée dans les méthodes d'analyse est démontrée comme essentielle pour l'analyse des houilles les plus récentes. On fait également remarquer qu'aucun projet de classification ne pourra être adopté universellement s'il ne s'applique à constater les propriétés du charbon renfermant de l'humidité.

CZECHOSLOVAKIAN LIGNITE: ITS PREPARATION AND UTILISATION

CZECHOSLOVAKIAN NATIONAL COMMITTEE, WORLD POWER CONFERENCE

DR. J. FORMÁNEK

Paper No. 46

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LIGNITE DEPOSITS — COMPOSITION — MARKETS — BRIQUETTING—BRIQUETTES—HIGH-TEMPERATURE CARBONISATION—LOW-TEMPERATURE CARBONISATION—STATE OF INDUSTRY—GASIFICATION—STEAM RAISING

ZUSAMMENFASSUNG

Introduction

Lignite is often called the fuel of the future, but the enormous reserves of it in the world, quantitatively being not much less than the coalfields, until now have been very little exploited. The mining of lignite is practically confined to the European continent, though its basins in Europe constitute scarcely 2 per cent. of the lignite reserves of the world, which in the main are concentrated in North America. The other countries, besides Europe, produce only about 3 per cent. of the world's lignite production, and Czechoslovakia holds second place to Germany.

Lignite is a low-grade fuel, therefore the direct utilisation of lignite is limited to the vicinity of the lignite mines. In order to extend the market for lignite, efforts are being made to prepare concentrated fuel from it. Briquetting without binders is successful, technically and economically, in Germany, but the increase of lignite carbonisation is checked by the difficulty of extending the market for lignite char. In countries outside Europe, the methods successfully tried in Germany have then been tried,

especially in North America and Australia, but they found that the processes applied in Germany to the earthy, plastic type of lignite—brown coal—are not equally applicable to lignites of other composition and structure. Most of the lignite fields in the world, especially those in North America, contain the hard type of lignite, the utilisation of which we find developed to the most important degree in Czechoslovakia.

Lignite Deposits

Of the lignite deposits in Czechoslovakia, shown in Fig. 1, the most important, economically, lie near the north-western frontier of Bohemia, and consist of two basins: (1) the basin of Teplice—Most—Chomutov, and (2) the basin of Karlovy Vary—Falknov—Cheb. The other lignite fields, Handlová in Slovakia, Hodonín in Moravia, and Mydlovary in Bohemia, are less important, as they yield only 3-4 per cent. of the whole lignite production. Besides the lignite industry, Czechoslovakia has also an equally important coal industry. The basin of Ostrava—Karvinná produces about three-quarters, other districts—Kladno, Plzeň, Svatoňovice in Bohemia, and Rosice in Moravia—supply the remainder of the coal production.

In Czechoslovakia were mined:—

Year	Lignite	Coal.
	Millions of tons.	
1913	23·1	14·2
1925	18·8	12·7
1926	18·8	14·5
1927	20·0	14·7

The average quantity per capita mined in 1925 was, in Czechoslovakia, 0·9 tons of coal and 1·4 tons of lignite, in comparison with 5·6 tons of coal in England, 2·2 tons of coal and 2·3 tons of lignite in Germany, and 1·2 tons of coal in France.

The lignite reserves in north-western Bohemia are estimated at 12,000 millions of tons. About one-third of the lignite production is mined in open cuts. Most of the lignite mined is a hard, dull lignite—in Canada called brown lignite. In addition, high-grade lignites are exploited from local deposits in considerable quantities: bright lignite (in Canada called black lignite) north of the line Most—

Fig. 1. Lignite and Coal Deposits in Czechoslovakia.

Duchcov, and gas lignite (called boghead lignite) of the Agnes seam in the district of Falknov.

Some small deposits of wax brown coal (in Germany called Schwelkohle) situated on the border of the basin of Karlovy Vary—Falknov—Cheb, are used partly for the manufacture of montan wax in two plants, only one of which is now being operated, with a production of 400-500 tons of montan wax per year, partly for distillation. The only plant in Czechoslovakia. Bituma at Zweifelsreut, near Cheb, with twenty-four modern Rolle ovens, erected in 1925, is working in a restricted measure (six to twelve ovens), as the market for lignite char (called Grudekoks) is not sufficient. There are hopes of briquetting lignite char successfully with binder.

Composition

The following table shows the variations in the composition of typical lignites of north-western Bohemia :—

Lignite.	In the raw lignite.				In the combustible matter.			
	Moisture per cent.	Ash per cent.	Carbonised residue per cent.	Heating value B.Th.U. per lb.	Bitumen per cent.	Fixed carbon per cent.	Volatile matter per cent.	Heating value B.Th.U. per lb.
Dull, hard Lignite (Brown Lignite) Poor Quality	35·9	8·2	—	6,370	—	—	—	12,060
Middle ,,	30·3	4·1	35·4	7,750	2·78	47·7	52·3	12,310
Good ,,	23·3	5·7	—	9,090	—	—	—	13,160
Bright Lignite (Black Lignite)	17·5	1·4	40·1	10,410	5·6	47·8	52·2	13,070
Boghead Lignite	16·6	6·2	27·9	10,380	*	28·1	71·9	13,670

Remarks: *F. Schulz has found in two samples of boghead lignite 12·6 and 15·5 per cent. respectively of bitumen.

Compared with the German brown coal with 50-60 per cent. moisture and 3,200-4,500 B.Th.U. per lb. heating value, and with the briquettes manufactured from the same with an average heating value 8,700 B.Th.U., the heating value of the Bohemian lignite varies mostly between 6,000–11,000 B.Th.U. per lb., being on an average equivalent to that of the German lignite briquettes.

Markets

The Bohemian lignite is almost exclusively used as fuel without any preparation. Its consumers (besides the lignite mines themselves), averaging the years 1924-1926, were:—

Export	15·8 per cent.
Industry	42·6 ,,
Railways and steam navigation ...	17·1 ,,
Household and agriculture	20·9 ,,
Briquetting	2·4 ,,
Distillation and carbonisation ...	0·2 ,,
Others	1·0 ,,
	100·0 ,,

The best consumer of lignite is the industry situated in North Bohemia. Because of its low price householders also prefer lignite to coal, the relative consumption being 20·9 per cent. of lignite, and 5·4 per cent. of coal. An important factor in the lignite market is its export, mostly to Germany, and amounting to not quite 3 millions of tons per year lately, whilst 7-8 millions of tons were exported before the world war.

The efforts to improve Bohemian lignite commenced with the smallest sizes, slack and nuts III (0-10 mm.), which formerly were mostly dumped as waste. During and after the world war, when fuel became scarce, industry got accustomed to the use of lignite slack, which for the last three years has found a good market in consequence of its low price. Thus, a great deal of the former inducement for the preparation of improved fuel out of the North Bohemian lignite was lost.

BRIQUETTING

Briquetting without Binder

The oldest way of improving Bohemian lignite is briquetting. The first briquetting plant was established in 1877 at Cukmantl, near Teplice. It manufactured household briquettes from lignite slack without binder, but the plant was closed a few years after its start. At present there exist in north-western Bohemia three plants for briquetting lignite without binder, but only two of them are working. The last one was built in 1906 and since that time no more briquetting plants have been installed, except a small trial press. These three briquetting plants use three different kinds of lignite.

The briquetting plant of the Königsberger Kohlen- und Brikettwerke at Pochlovice, near Falknov, has twelve Exter presses with a capacity of 600 tons of briquettes per 24 hours, which manufacture briquettes with an estimated pressure of about 1,300 atmospheres from a lignite of the earthy type. It is a medium hard, earthy brown coal, enclosing small layers of wax-brown coal. The dried lignite is cooled intensively before briquetting. Both as to the physical and the chemical characteristics and as to the methods of working, this plant differs in nothing from the German plants briquetting brown coal. The composition of the lignite used at Pochlovice is shown by the following two proximate analyses:—

		I.	II.
Moisture	per cent.	41·30	47·52
Ash	,,	3·30	3·17
Combustible matter ...	,,	55·40	49·31

The composition of the manufactured briquettes is stated to be:—

Moisture	16·20 per cent.
Ash	5·92 ,,
C	56·52 ,,
H	5·54 ,,
O	15·42 ,,
S	0·40 ,,
Heating value	... 10,000 B.Th.U. per lb.

The second briquetting plant, established by the Zieditz-Habersbirker Braun- und Glanzkohlenwerke at Habersbirk, near Falknov, has seven Exter presses, which are strengthened by traverses and anchor screws against the high pressure in the mould of approximately 2,000 atmospheres. The capacity of this plant is 280 tons of briquettes per 24 hours. The lignite used here is a mixture of two hard lignites from two different seams, called Lignite seam and Agnes seam, with the following composition, according to an older analysis:—

			Lignite Seam	Agnes Seam
Moisture	per cent.		43·6	32·6
Ash	,,		6·4	5·4
Fixed Carbon... ...	,,		31·0	32·6
Volatile Matter	Tar ...	,,	6·6	14·8
	Gas ...	,,	7·8	10·6
	Water ...	,,	4·6	4·0
			100	100

More recent analyses are:—

		Lignite Seam	Agnes Seam
Moisture	per cent.	40·13	23·51
Ash	,,	2·87	3·24
Heating value B.Th.U. per lb.	...	7,580 (?)	10,400–11,200

The Agnes lignite is rich in volatile matter and has a high percentage of bitumen and tar. W. Hentze has found in a dry sample of Agnes lignite 17·6, and in the lignite from the Lignite seam, 7·6 per cent. of matter soluble in a mixture of benzene with 10 per cent. of methyl alcohol. The Agnes lignite is very suitable, but the lignite of the Lignite seam is not so suitable for briquetting without binder. The quality of the manufactured briquettes depends on the proportion in which both lignites are mixed. Special apparatus for cooling the dried lignite mixture before briquetting is not installed. The arrangement of this briquetting plant also does not differ from that employed in the German briquetting method, except that the presses are strengthened against the very high pressure. It is likely that the high bitumen content in the Agnes lignite makes the lignite mixture

plastic to such a degree, as is essential for its briquetting without binder under very high pressure. According to an old analysis from Dr. H. Langbein the composition of these briquettes (the normal content of moisture is 11-12 per cent.) is:—

Moisture	4·21 per cent.
Ash	9·03 ,,
C	64·53 ,,
H	5·95 ,,
O	14·50 ,,
S	1·78 ,,
Heating value	... 11,400 B.Th.U. per lb.

The third of the existing briquetting plants is that of Česká Obchodní Společnost (Böhmische Handelsgesellschaft) at Křemyž, near Teplice. This plant, erected in 1906, was in operation until 1917, and then again from 1922 to 1925, when it ceased working. Only one 6-in. press had been installed by the Engine Works Breitfeld, Daněk Co., at Slaný, near Prague, for the intended production of 15,000 tons of briquettes per year. The lignite used here is hard, with a low bitumen content, and had about 35 per cent. moisture, 7-8 per cent. ash, and heating value 6,700 B.Th.U. per lb. The combustible matter of this lignite contained 2·7 per cent. of matter soluble in benzene. The briquettes had 15 per cent. moisture, 10·2 per cent. ash, and a heating value of 9,130 B.Th.U per lb.

For briquetting this hard lignite, poor in bitumen, without binder, the Engine Works Breitfeld, Daněk Co. have modified the German method. As Fig. 2 shows, the lignite screenings first pass a roll crusher *a* and then a shaking screen *b*. The fine lignite (size 0-5 mm.) drops into the hopper *c*, from which it is carried by a bucket elevator *d* into a Schulz dryer *e*. The dried lignite by a second roll crusher *f* is reduced to the size of 0-3 mm., and passes the heater *h*, consisting of two steam jacketed cylinders. The dried lignite is forced by worm conveyors through the heater and is delivered, heated to about 100-120°C., into a steam-jacketed hopper over the press *k*. The difference between the press used in this plant and the normal German Exter press, is that the stamp is driven from the fly wheel shaft, not directly by an eccentric rod, but by a system of levers. Thus the characteristics of the Bohemian lignite briquetting method are the heater and the driving mechanism of the stamp. In the heater the lignite becomes somewhat plastic, and the particular driving mechanism renders the motion of the stamp during the pressing of lignite to a briquette approximately 60 per cent. slower

than if the stamp is driven directly by the rod. Thus the dangerous strokes in the press are moderated, the air has more time to escape from the lignite, and the briquette is under pressure for a longer time. The pressure in the press amounts to 2,000 atmospheres, though it has often been stated that it reached 3,000 atmospheres. During the manufacturing period of fully thirteen years, the production surmounted only once 50 per cent. of the designed

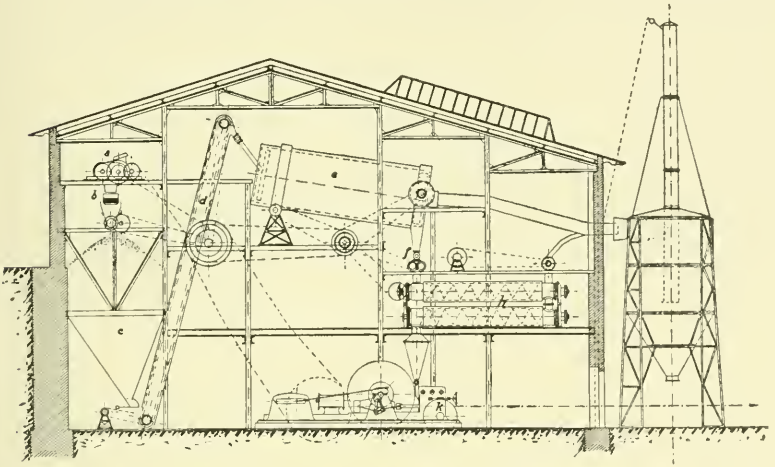


Fig. 2. Lignite Briquetting Plant at Křemyž.

capacity, and on an average was scarcely 30 per cent. of it, due chiefly to the insufficient demand for these briquettes.

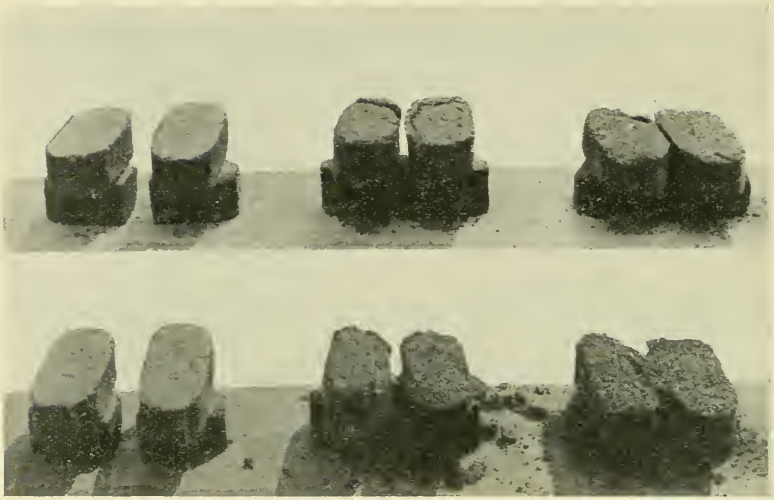
The yearly briquette production in Czechoslovakia amounts now to approximately 200,000 tons, 70 per cent. of which are exported to Germany. The briquetting of lignite, therefore, is relatively an important factor in its export. About 2 per cent. of the Bohemian lignite production is utilised by briquetting.

Briquetting with Binders

The failure in the efforts of briquetting the hard Bohemian lignite with low bitumen content, without binder, caused the installation of three briquetting plants producing boulets (ovoid briquettes) from lignite slack with lignite or coal tar pitch. These plants were established during and immediately after the world war, when fuels were scarce, but all of them have stopped working in recent years.

Quality of Bohemian Lignite Briquettes

Briquetting of the hard Bohemian lignite containing little bitumen without binder, produces briquettes which are strong enough to

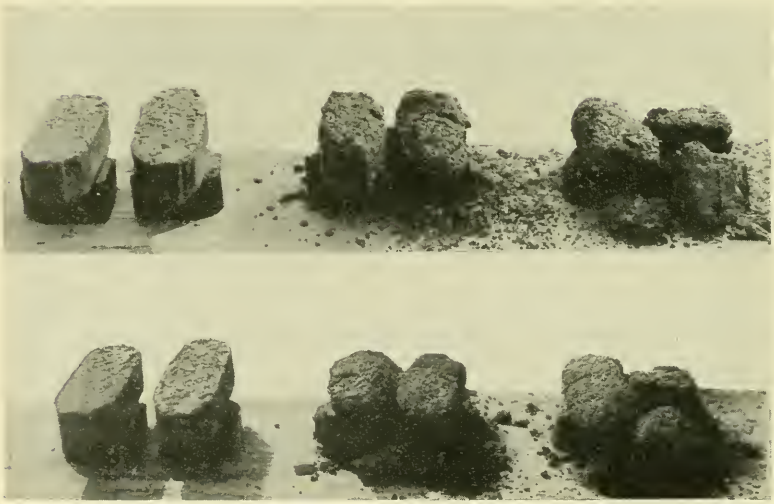


After 7 days.

After 15 days.

I. II. III.

Fig. 3a.



After 30 days.

After 50 days.

I. II. III.

Fig. 3b.

Weathering Tests with Bohemian Lignite Briquettes.

handle, but which are not sufficiently weatherproof and do not hold together in the fire. Neither the pulverising of lignite (to a size 0-1 mm.), nor its heating before briquetting, are able to remedy these deficiencies materially. Fig. 3 illustrates the weathering test of the three described types of Bohemian lignite briquettes exposed in summer to the open air for fifty days. In order to quicken this test all the briquettes were often sprinkled with water regularly and equally. The photographs show the excellent weather-resisting quality of the standard briquettes of Habersbirk (I.) from a hard lignite rich in bitumen. The weathering test of these briquettes was then continued for a whole year (without the additional spray), and no further disintegration of any importance could be observed. The tested briquettes of Pochlovice (II.) were fourteen days old, while the briquettes of Křemyž (III.) were more than a year old, and had gained much in their weather-resisting quality by the long storage. The briquettes of Pochlovice and Habersbirk stand the heat well, but the briquettes of Křemyž disintegrate in the fire. The boulets manufactured from lignite slack with lignite tar pitch, though they are waterproof, also disintegrate in the fire.

CARBONISATION

High-Temperature Carbonisation

The most important progress in the efforts for the preparation of improved lignite in Bohemia was the carbonisation, especially the manufacture of *kaumacite*, a lignite char, produced by high temperature carbonisation of lignite.

The first kaumacite plant was the Koks- und Kaumazitwerke C. Melhardt, at Veselí, on the Elbe River, near Ústí later taken over by Dr. Auspitzer. This enterprise was financed by Haller, Söhle Co., of Hamburg, and worked in 1898-1908. Originally, this plant was established for the carbonisation of English coal only, imported *via* Hamburg. For this coal carbonisation the Appolt vertical oven was installed. When, during the Boer war, the import of English coal became difficult, the carbonising plant began to work up lignite instead. For the carbonisation of lignite the Appolt oven was modified on the principle of the Rolle oven. The upper section of the Appolt retorts was provided with a double series of cast-iron overlapping plates (Fig. 4), for drawing off the gas and the vapours produced by the lignite carbonisation.

The kaumacite plant at Veselí had six batteries of retorts with a capacity of approximately 300 tons of lignite per day. The kaumacite was used partly as boiler fuel, especially in Germany, and partly

for the manufacture of kaumacite briquettes, with lignite tar pitch as binder. These briquettes were sold for household purposes and steam navigation. Tar and ammonia were recovered. By distillation of lignite tar motor oil, lighting oil, oils for extraction and impregnation and pitch used for briquetting were gained.

As the geographical situation of this first kaumacite plant at Veselí, far away from any lignite mines, was economically unfavourable, the production of kaumacite was transferred to the immediate neighbourhood of lignite mines, partly to Ervěnice, near Most, and partly to Světec, near Duchcov. The plants at Veselí and Ervěnice were abandoned after the immense failure of Haller, Söhle Co.

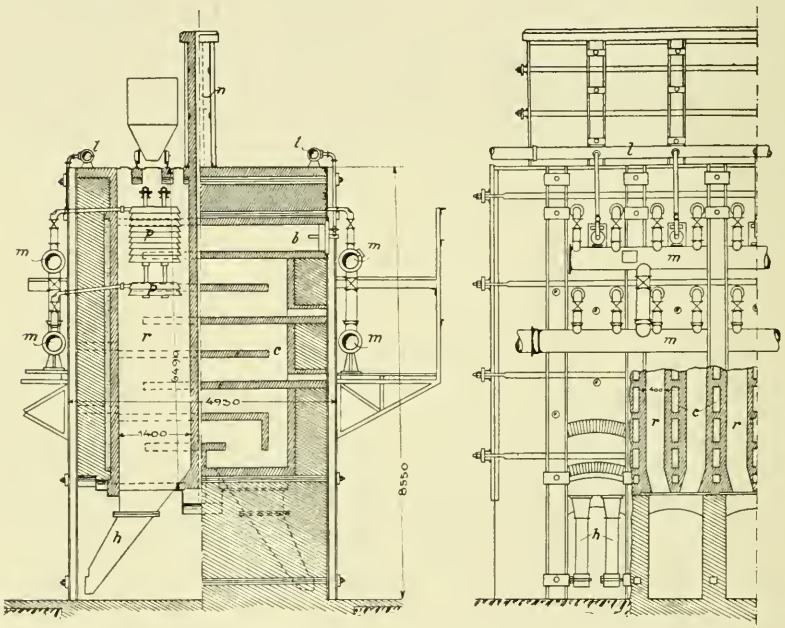


Fig. 4. Kaumacite Oven for High-temperature Carbonisation of Bohemian Lignite.

The production of kaumacite in the Weinmann works at Světec, near Duchcov, became more important than at Veselí. The plant at Světec has six batteries of kaumacite ovens, or 220 retorts. Its capacity is about 320 tons of lignite per day. Three batteries were installed for the carbonisation of lignite nuts II. and III. (size about 5-20 mm.), see Fig. 4. The kaumacite oven has two parallel series of vertical retorts *r*, made of refractory material, which are 6,490 mm. high and in the horizontal section, 1,400 mm. long and 400 mm. wide.

The total height of the oven is 8,550 mm., and its total breadth 4,930 mm. The cast-iron overlapping plates *p*, serve for drawing off the moisture and the gas with the tarry vapours from the retorts, into the collecting mains *m*. From the cooling hoppers *h*, kaumacite is discharged at regular intervals, and after having been quenched in water it is screened. Between the retorts are the heating chambers *c*. The heating gas is brought by the gas line *l* to the burners *b* at the top of the heating chambers, and the hot gases of combustion passing the horizontal heating flues are drawn off downwards by the chimney *n* into the open air. The lignite passes through the retort in about 24 hours. The temperature of carbonisation reaches 1100°-1300°C.

The other three batteries of retorts are installed for the production of kaumacite from lignite slack. For this purpose the overlapping plates are made of refractory material and transferred from the inner part into the narrow walls of the retorts, both on the outside and in the middle of the oven. Instead of the overlapping cast-iron plates, heating pipes made of refractory material are put into the upper section of the retorts and communicate with the heating chambers. Thus the difficulty of swiftly and uniformly heating the whole mass of the compactly lying fine lignite is overcome. The waste gases pass from the heating chambers through recuperators and warm the air for the burners. The kaumacite retorts for lignite slack are charged with dried lignite. For drying lignite slack three direct-heat rotary dryers were, in 1912, installed by Möller & Pfeifer, of Berlin, heated with pulverised lignite. Each dryer has a capacity of 13 tons of lignite slack dried from 30 per cent. to 10 per cent. moisture per hour.

For the production of kaumacite they used lignite having approximately 30 per cent. moisture and a heating value of 7,600 B.Th.U. per lb. Kaumacite is a hard lignite char, though cracked, yet strong enough. It is a smokeless fuel difficult to ignite. Samples sent by consumers to the Geological Institute of Vienna showed the following composition:—

C per cent.	H per cent.	O + N per cent.	S per cent.			H_2O per cent.	Ash per cent.	Heating value (calculated) B.Th.U. per lb.
			Combustible.	Ash S.	Total S.			
78·54	0·72	0·92	0·12	1·17	1·29	6·85	12·85	11,740
79·72	0·88	0·93	0·17	1·07	1·24	6·35	11·95	12,030

Kaumacite was screened in three sizes, 0-4, 4-8, 8-16 mm. The finest size (0-4 mm.) was used for the manufacture of kaumacite

briquettes with lignite tar pitch as binder. The larger sized lignite char was burned in boiler furnaces, especially in Germany. The largest size (8-16 mm.) of kaumacite was also used as fuel for suction-gas producers. During the world war, "semi-coke" briquettes were manufactured from a mixture of kaumacite and dried lignite with pitch. These briquettes were easy to ignite and free-burning, and were used as household fuel.

Tar and ammonia were recovered as by-products of the lignite carbonisation. The yield of tar was 3-3½ per cent. of the raw lignite quantity, the yield of ammonia amounted scarcely to 10 per cent. of the nitrogen content in the lignite. The tar was sold to Germany. The purified gas of 390-440 B.Th.U. per cu. ft. was used for the heating of kaumacite retorts and ovens in zinc works, and for the driving of gas engines.

The kaumacite production of the Weinmann works in the years immediately preceding the world war, was approximately 40,000 tons per year, for which amount 100,000 tons of lignite were consumed. The carbonising plant worked from 1907 until 1919. In 1919 the kaumacite ovens, left without attendance during a strike, were damaged, and the production of kaumacite was not taken up afterwards.

Low-Temperature Carbonisation

Though the low-temperature carbonisation of Bohemian lignite did not reach the same importance as its high-temperature carbonisation the experiments made by the Brüxer Bergbaugesellschaft, in co-operation with the Engine Works Ringhoffer, of Prague, on the Alexander Mine, near Duchcov, in 1906-1912, are worth recording. Slack of high-grade lignite (heating value of 9,000-10,000 B.Th.U. per lb.) was treated by a low-temperature carbonisation process designed by Bock. The lignite char produced was briquetted with sulphite liquor and the briquettes were made weatherproof by a second carbonisation, in order to carbonise the binder in the lignite char briquettes. The carbonised briquettes, having a heating value of 12,300-13 300 B.Th.U. per lb. compared with the kaumacite briquettes, should represent an absolutely smokeless fuel, being easy to ignite and consequently having a larger saleability.

Favourable results with an experimental apparatus for a 10-tons production per day led to the establishment of a plant with a capacity of 100 tons of briquettes in 24 hours. For the low-temperature carbonisation of lignite, three horizontal, cylindrical retorts, made of steel plates, were set one beneath the other. Paddles

attached to a rotating, centrally located shaft in each retort, forced the lignite through all the retorts, one after another. The lignite char was then pulverised, mixed with sulphite liquor, and rectangular briquettes with 50 mm. long sides were made of this mixture in a Tigler press. Sixty-four briquettes manufactured at each stroke of the press stamp were set up on trays. Five trays with briquettes were put into a cassette. Every two cassettes were hung up by a pin on an endless chain. The bottoms of both cassettes, belonging together, were connected by a plate closing the oven. The cassette conveyor carried the wet briquettes up and down over drums through an oven, where the binder was carbonised, and the briquettes were then cooled down before leaving the oven. Tar and ammonia were recovered as by-products, and the purified gas was used for heating both the retorts and the briquette dryer.

This plant suffered by frequent interruptions and by the varying quality of the manufactured briquettes. As these difficulties could not be overcome, the young plant was soon closed down. The lowest and last retort and its paddle shaft were distorted by overheating, and the oven for the carbonisation (or drying) of the briquettes was also damaged. The carbonised lignite char briquettes were sometimes of excellent shape, strength and weather-resisting quality, but at other times they were cracked, crumbled to pieces, disintegrated in water and ignited spontaneously.

The Bock carbonising process may be called the predecessor of C. H. Smith's Carbocoal process, which was tried in the United States of America in 1919-1922. Both processes entailed twofold carbonisation and briquetting with binder. Of course, the carbonisation or drying of the wet lignite char briquettes in the Bock process was done only at a low temperature, approximately 300°C.

The experiments conducted by the Bureau of Mines of the U.S.A., in co-operation with the Lignite Utilisation Board of Canada, for the manufacture of lignite char briquettes, are successors to the Bock process. Though they are reported to have been developed to a condition for commercial application, they are, as yet, not commercially successful.

The Present State of Lignite Carbonisation in Czechoslovakia

At present the carbonisation of north-western Bohemian lignite is developed only in a small way. Some of the gasworks situated in this lignite district use lignite for the manufacture of town's gas in horizontal retorts at 900-1,100°C., as a substitute for coal.

Lignite, with 31·5 per cent. of moisture and 4·5 per cent. of ash, and with a heating value of 7,600 B.Th.U. per lb., yields 8,100 cu. ft. of gas of 480 B.Th.U. per cu. ft. gross heating value, approximately 40 kilos of tar and 450 kilos of lignite char quenched by water per 1 metric ton. Lignite char, a great deal of which is breeze, is partly gasified in producers for heating retorts, the remainder is sold as boiler fuel, reducing agent in zinc works, and as material for the manufacture of paints.

The Zinc Works Dudek Bros., at Řetenice, near Teplice, produce lignite char for their own reducing purposes at a carbonising temperature approximately as high as that in the Rolle oven. The only Czechoslovakian plant for distillation of wax brown coal at Zweifelsreut was mentioned above.

Gasification

An important branch of the utilisation of north-western Bohemian lignite is the manufacture of producer gas in glass works and in metallurgical and chemical factories. About 2 per cent. of the whole lignite production is now worked up in Bohemia by the producer gas process.

Among the gas producers used for lignite gasification, those of Mond are the most important. A Mond gas producer plant having twelve units was established in 1912 by the Mannesmann Works at Chomutov. Another plant with fourteen producers is manufacturing gas in the Weinmann Works at Světec, near Duchcov, for glass and zinc works. A Mond producer has a capacity of 20-25 tons of lignite treated in 24 hours. The air and steam composing the blast are superheated to 300°C. The blast contains approximately 0·5 kilo of steam for 1 kilo of lignite. From the raw producer gas tar is obtained at its practically full yield, and also ammonia, which is absorbed by a weak solution (about 2 per cent.) of sulphuric acid. The yield of ammonia corresponds to approximately 60 per cent. of the nitrogen content in the lignite.

The Mond gas producer plant at the Mannesmann Works uses low-grade lignite, which has 30·5 per cent. moisture, contains 31·82 per cent. of ash, and 0·81 per cent. of nitrogen in the dry lignite, and has a heating value of about 5,400 B.Th.U. per lb. From 1 metric ton of gasified raw lignite are recovered 45,000 cu. ft. (at 0°C. and 760 mm.) of gas of 158 B.Th.U. per cu. ft., 66·4 kilos of tar and 16·5 kilos of ammonium sulphate. One ton of lignite, consumed by gas producers and the boiler plant belonging to them, yields 32,650 cu. ft. of gas available for metallurgical works,

49·4 kilos of tar with 5 per cent. water, and 12·5 kilos of ammonium sulphate. The recovered tar is partly used as fuel for heating metallurgical ovens, and partly utilised by distillation, which yields oil for heating and impregnation purposes and pitch.

The other gas producer plant at the Weinmann Works manufactures gas out of nuts I-III (size 5-40 mm.) of lignite, with approximately 30 per cent. moisture and 12 per cent. ash. The producer gas has 180 B.Th.U. per cu. ft. heating value. The lignite tar recovered was at first treated in a distillation plant working continuously. Lignite tar oils were mostly exported to Germany; pitch was utilised in their own lignite briquetting plant. At present tar is sold to the Bituma, Society for Chemical Industry at Karlovy Vary.

From the other gas producer plants recovering only tar as a by-product, the plant of the Glass Works J. Inwald, at Cukmantl, near Teplice, consisting of eight Koller producers with revolving grates, has to be mentioned. A Koller producer treats 25-30 tons of lignite in 24 hours with a high thermal efficiency. The gasified lignite of the Charles Mines contains about 35 per cent. moisture, and 4·5 per cent. ash, its heating value is approximately 7,200 B.Th.U. per lb. and yields 77,700 cu. ft. (at 35°C. and 736 mm.) producer gas of 175 B.Th.U. per cu. ft., and 100 kilos of tar with 3 per cent. of water per metric ton. The distillation plant at Venier Cukmantl manufactures from this lignite tar fuel oil, approximate yield 12 per cent., phenol oil 28 per cent., and pitch 55 per cent. The quantity of light oil is very small, about 1 per cent.

The Glass Works Mühlig - Union, at Řetenice and Hostomice, near Teplice, use fourteen Grosse producers for gasification of lignite and sell the recovered lignite tar to the Bituma. The Verein für Chemische und Metallurgische Production at Ústí has nine Kerpely gas producers at work, and the Industrie - Werke (formerly J. D. Starck) at Dolní Rychnov, near Falknov, are working with twenty-seven Heller producers for glass manufacturing purposes.

Besides the distillation plant of Venier, lignite tar is treated by the Bituma in the distillation plant at Kralupy, near Prague. There are manufactured two fractions of tar oil, paraffin oil and phenol oil. The first oil is exported to Germany and the second to Australia.

Use of Waste and Low-Grade Lignite for Steam Raising.

Some electric works situated in the Bohemian lignite district, especially the large power station at Ervěnice, near Most, producing electric energy for Prague, use waste lignite of high ash content for

steam raising. For this fuel the Lomšakov grate proved to be very suitable.

The use of lignite in pulverised form in Czechoslovakia is still in its initial state of development. In this respect the Babcock boiler plant in the electric works of the town of Ústí is working with the best results. Two other power plants, one at Mydlovary in South Bohemia, and the other one at Handlová in Slovakia, have not yet overcome the initial difficulties.

REMARKS

In this report the English-American nomenclature has been used, but in Czechoslovakia, as in Germany, lignite generally is called *brown coal.* In the Czechoslovakian terminology "lignite" means only one class of brown coal, which is characterised by its distinct woody structure, but this class of brown coal does not play any part in the Czechoslovakian production of brown coal.

ZUSAMMENFASSUNG

Die Tschechoslowakei steht an *zweiter* Stelle in der Weltförderung der Braunkohle. Gegenwärtig beträgt die tschechoslowakische Braunkohlenproduktion fast 20 Millionen Tonnen jährlich. Die in Nordwestböhmen gewonnene Braunkohle gehört dem *harten* Typus an zum Unterschiede von der deutschen weichen Erdbraunkohle. Die Qualität der böhmischen Braunkohle ist recht ungleichmässig, indem ihr unterer Heizwert ungefähr zwischen 3 500 und 6 000 W.E. schwankt. Durchschnittlich ist die böhmische Braunkohle den deutschen Braunkohlenbriketts gleichwertig.

Die böhmische Braunkohle wird fast ausschliesslich im rohen Zustande als Brennstoff verbraucht. Ihre grössten Konsumenten sind die nordböhmische Industrie, der Hausbrand und der Export, vorwiegend nach Deutschland.

Die *Veredelung* der Braunkohle bildet zwar gegenwärtig keine wirtschaftlich besonders wichtige Grundlage der böhmischen Braunkohlenindustrie, im Gegensatze zu Deutschland. Auch in Nordamerika gilt dieselbe als *conditio sine qua non* für eine intensive zukünftige Ausnützung der riesigen Braunkohlenvorräte. Trotzdem sind die Brikettierung und Verkokung der Braunkohle in der Tschechoslowakei, welche in grossem Masstabe und in lang dauerndem Betriebe durchgeführt wurden, mehr als blosse Versuche und daher beachtenswert besonders deshalb, weil hier eine Braunkohle verwertet wurde, welche in ihrer Zusammensetzung und Struktur den nordamerikanischen Braunkohlen viel näher steht als die deutsche Braunkohle.

Den Anlass zur Veredelung gibt in der Tschechoslowakei nur die Abfallbraunkohle. Es sind dies die Braunkohlenlösche und die aschenreichen Braunkohlenarten.

Die *Braunkohlenlösche,* welche vor dem Weltkriege meist unverkäuflich war, hat man als billigen Rohstoff für die Brikettierung, Verkokung und Schwelung zu verwerten versucht. Jetzt findet die Braunkohlenlösche als Kesselheizstoff in der Industrie guten Absatz, so dass der frühere Impuls für ihre Veredelung zum grossen Teile wieder verloren ging.

Die *Brikettierung ohne Bindemittel* hat sich für die harte und bitumenreiche Braunkohle in Habersbirk bewährt. Hingegen gelang es nicht, aus der normalen, harten und bitumenarmen böhmischen Braunkohle nach dem für sie besonders ausgearbeiteten *Verfahren der Maschinenfabrik Breifeld, Daněk Co.* in Slaný ohne Bindemittel Briketts von der gewünschten Qualität zu erzeugen. Es blieb nur bei einer Versuchsanlage, welche nicht mehr im Betriebe ist. Die Brikettierung der Braunkohle *mit Pech* hat sich unter normalen Absatzverhältnissen als unwirtschaftlich erwiesen.

Eine für die böhmische Braunkohle typische Veredelungsmethode ist die *Kaumaciterzeugung* durch Hochtemperaturverkokung. Sie wurde über 20 Jahre betrieben, ist jedoch seit dem Jahre 1919 aus wirtschaftlichen Gründen nicht mehr aufgenommen worden. Einige nordwestböhmische *Gaswerke* benützen die Braunkohle als billigen Ersatz für die Steinkohle zur Leuchtgaserzeugung.

Der interessante Versuch der *Schwelung* der böhmischen Braunkohle nach dem *Verfahren von Bock* am Alexanderschachte bei Dux kann als Vorgänger sowohl des alten Carbocoal-Verfahrens als auch der gemeinschaftlichen Versuche des Bureau of Mines, U.S.A., und des Lignite Utilisation Board of Canada bezeichnet werden.

Die *aschenreichen Braunkohlenarten* können natürlich als Rohmaterial zur Erzeugung eines veredelten festen Brennstoffes nicht dienen. Man kann jedoch ihre *Vergasung* wegen der Gewinnung des Teers bzw. des Ammoniumsulfats als Nebenprodukte, deren Wert manchmal den Preis der vergasten Kohle reichlich deckt, gewissermassen als einen sehr zweckmässigen Veredelungsprozess bezeichnen. Unter den für die Vergasung der böhmischen Braunkohle verwendeten Gasgeneratoren sind die von *Mond* und *Koller* die wichtigsten. Allerdings trägt die Verarbeitung des *Braunkohlengeneratorteeres* zur Deckung des Bedarfes an leichten Treibölen und Schmierölen noch nicht bei.

Die Verwertung der *aschenreichen Abfallbraunkohle zur Kesselheizung* hat in der letzten Zeit wesentliche Fortschritte gemacht. Die *Braunkohlenstaubfeuerung* ist derzeit nur mit einer im Betriebe bewährten Anlage vertreten.

PRINCIPES DE L'UTILISATION DE LA MATIÈRE ORGANIQUE DU CHARBON COMME ENGRAIS

(THE USE OF COAL AS A FERTILISER)

CZECHOSLOVAKIAN NATIONAL COMMITTEE, WORLD POWER CONFERENCE

A. D. KISSEL

Paper No. A7

CONTENTS

A NEW CONCEPTION OF HUMIC COMPOUNDS—REPLACEMENT OF THESE BY BROWN COAL—RESULTS OF EXPERIMENTS—RÉSUMÉ

Le charbon est une des matières principales pour la plupart des industries, étant employé comme combustible ou comme matière première de fabrication; il n'est pas sans raison de supposer que l'agriculture sera également obligée de s'intéresser à l'emploi du charbon, puisque le manque actuel d'engrais organiques naturels est sensible. Le charbon pourrait être employé à ce but soit comme moyen d'améliorer les qualités physiques du sol soit pour produire des engrais concentrés organo-minéraux ayant une teneur élevée en composés humiques et en azote.

Le rapport actuel ne s'occupe pas des problèmes de l'utilisation finale du charbon comme source de l'énergie potentielle, ces problèmes appartenant à l'art de l'ingénieur; il considère, au point de vue de l'agronomie, le charbon comme matière qui pourrait être transformée, sous l'influence des processus biochimiques, en produits organiques convenant à la nourriture de l'organisme humain ou animal. L'énergie potentielle du charbon ne serait donc pas transformée en une autre forme d'énergie applicable aux besoins de la technique, mais elle serait transporté sous une autre forme de substance matérielle.

Les problèmes de la participation de la matière organique se trouvant dans le sel (principalement sous forme du complexe des sels d'acide humique), aux processus du développement et de la nutrition des plantes ne sont pas nouveaux; c'est déjà M. Lomonossof dont l'attention a été attirée sur ces sujets, plus tard MM. Seaussure, Grandeux et beaucoup d'autres. Néanmoins, dès que la théorie dite

"minérale" s'est développée, avec ses principes de la nutrition des plantes d'économie rurale, l'évolution de la doctrine du composé organique du sel s'est considérablement atténuée.

Conformément aux principes de la théorie "minérale," le développement de l'organisme d'une plante est la fonction d'une influence harmonique des éléments nutritifs qui se trouvent dans le sol; cette théorie ne donne pratiquement que peu d'égard au rôle que jouent l'énergie thermique et chimique des rayons de soleil et la composition du mélange d'air atmosphérique. Il paraît qu'un réglage même partiel de ces derniers facteurs très importants dépassait les possibilités de la technique d'économie rurale; et bien que les savants aient fait beaucoup d'efforts à résoudre ces problèmes, les résultats de ces recherches ont eu peu d'application dans la vie pratique.

Néanmoins la circulation générale des réserves d'eau dans le terrain au temps de la période végétative et la forme de la courbe exprimant *le mouvement de la chaleur* dans le sol pendant les vingt-quatre heures sont d'une grande importance pour l'organisme de la plante. Parmi les facteurs qui influencent la formation de la matière organique, *l'acide carbonique* (CO_2) est encore important; il sert comme régulateur exclusif des processus de synthèse aussi bien que du cours de la vie générale et du développement d'organismes.

Ces trois facteurs, la chaleur, l'eau et l'acide carbonique, posent les conditions de développement d'un végétal et resolvent les questions des abondantes récoltes rurales; et pourtant, jusqu'à présent, ils ne jouissent guère de l'attention qu'ils méritent et ce sont exclusivement les forces de la nature qu'on laisse veiller sur la présence et le réglage de ces facteurs dans le milieu entourant la plante.

Par des recherches détaillées des terrains russes ayant beaucoup de humus on a trouvé que les *composés organiques* dans la substance de humus ont un rôle très important; en formant la partie essentielle des sols de cette espèce, ils se montrent comme régulateurs principaux des facteurs agissant sur la grandeur et le développement des plantes, et c'est l'une des causes principales de la fertilité des terrains de cette espèce.

L'analyse détaillée des influences directes et indirectes effectuées sur les couches du sol montre que le processus de la formation des "éléments de structure" du sol et l'augmentation de leur résistance mécanique aux instruments d'agriculture dépendent de la combinaison des composés humiques. La formation des "éléments de structure" elle-même est cause de la granulation et de la porosité du sol desquelles dépend *l'aération du sol*, si importante pour les

centres embryonaux du végétal (principalement pour les nodus), pour l'évolution des organes séparés et pour la formation d'une frondaison verte. La présence de la matière organique augmente en même temps l'évolution rapide de la *vie microbiologique* du terrain et accélère les processus biochimiques convertissant les éléments nutritifs de la cendre, non solubles dans l'eau, en des composés utilisables à la nutrition; ce sont surtout les procèssus de nitrification auxquels les substances humiques sont en particulier favorables.

Les composés humiques améliorent aussi, par leurs propriétés chimiques et physiques, le pouvoir du sol *d'absorber et de conserver l'eau:* la matière organique abandonne difficilement l'eau une fois absorbée ce qui rend le sol plus indépendant des conditions météorologiques du pays.

La présence de composés humiques abaisse encore la *conductibilité thermique* du sol et en fait augmenter la *chaleur spécifique.* Par suite d'un échauffement moins rapide et de pertes de température moins brusques, la courbe indiquant les variations de la température des couches arables dans les 24 heures est plus droite pour les sols contenant des matières humiques que pour ceux qui se composent exclusivement de matières minérales. L'amplitude de cette courbe est moins élevée et s'approche de l'amplitude optima de la courbe moyenne théorique ce qui est une des conditions les plus importantes pour un bon développement d'un organisme végétal. (Voir les diagrammes Nos. 1, 2, 3 et 4.)

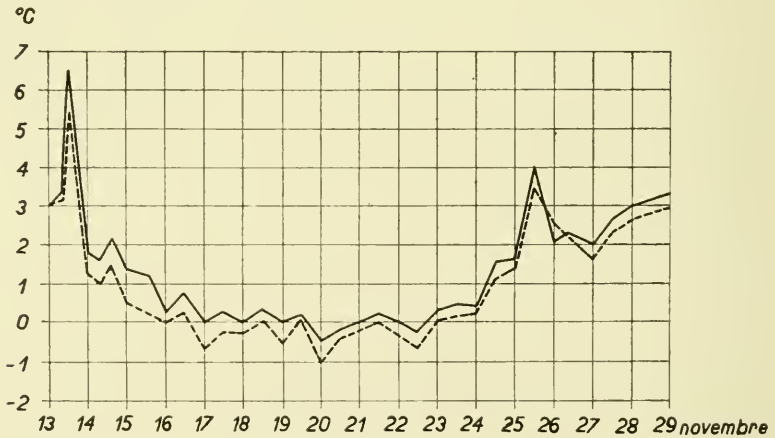


Diagramme No. I—Niveau calorique du sol—
---------- Sur une parcelle ordinaire (sans lignite).
———— Sur une parcelle préparée au lignite en poudre des mines de Hedvika (300 q. par ha.).

Observations faites au mois de novembre 1924 dans une profondeur de 5-10 cm.

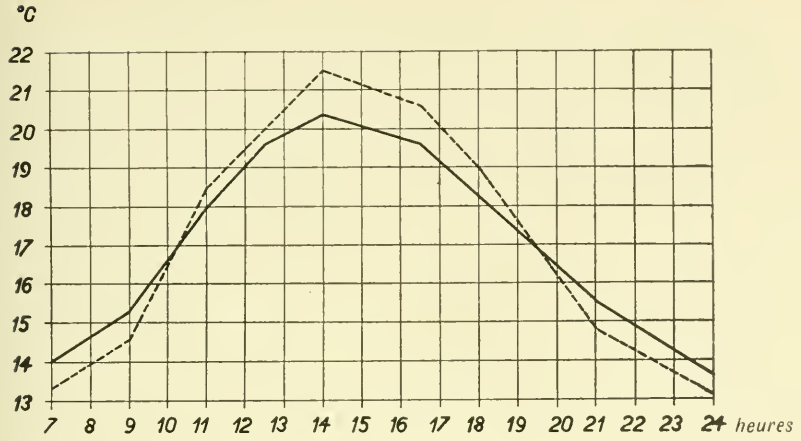


Diagramme No. II—Niveau moyen calorique du sol aux mois de juin et juillet dans une profondeur de 5-18 cm.
———— sur une parcelle préparée au lignite.
---------- sur une parcelle ordinaire (sans lignite).

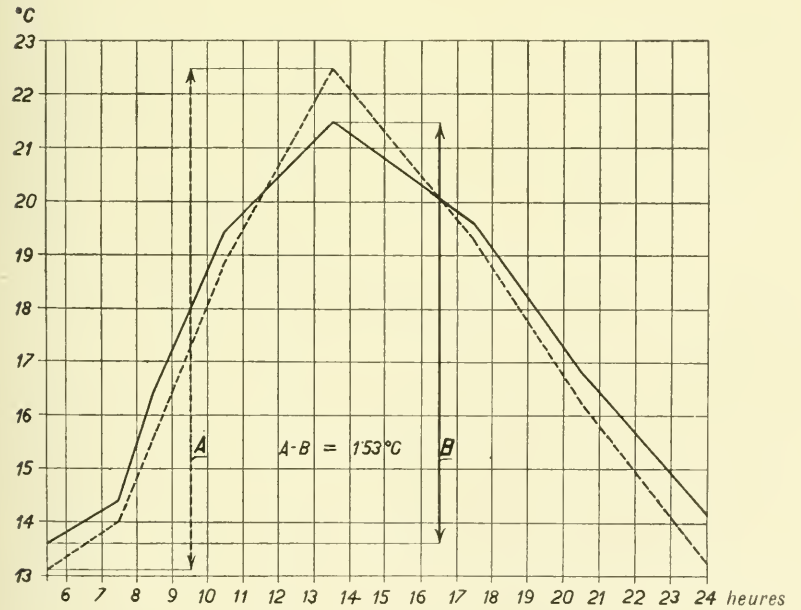


Diagramme No. III—Différence moyenne des amplitudes caloriques entre les sols—
(*a*) ---------- ordinaire
(*b*) ———— préparé au lignite
Observations faites du 1er au 15 juin 1924.

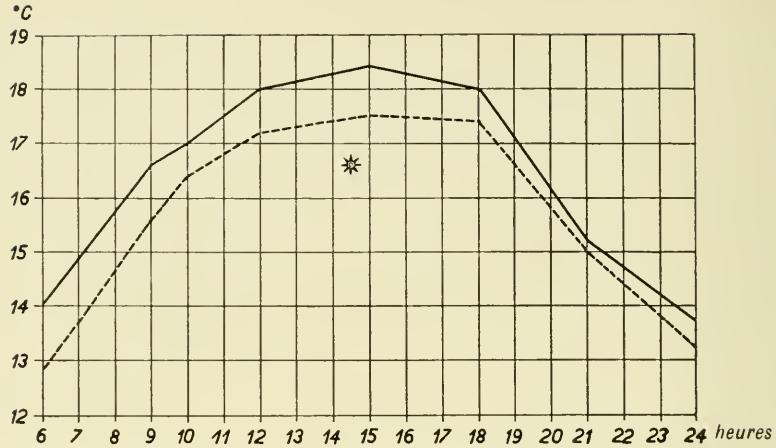


Diagramme No. IV—Exemple du mouvement calorique au sol—
———— préparé au lignite
---------- ordinaire.
Pendant un jour pluvieux typique (le 17 juin 1924).

Un autre rôle spécifique que jouent les composés organiques dans le sol, c'est la formation *d'acide carbonique* libre. Ce gaz se forme non seulement par la respiration des microorganismes du sol, mais il résulte aussi de la décomposition des matières organiques des microorganismes eux-mêmes; il agit sur les éléments pétrographiques du sol et fait augmenter la concentration de l'acide carbonique dans les couches de l'atmosphère adjacentes au sol. Parce que l'acide carbonique est plus lourd que l'air et que les blés s'opposent aux courants horizontaux de l'air, il se forme une couche immobile d'acide carbonique qui fait augmenter l'intensité des processus d'assimilation et la formation des produits élevées de l'assimilation dans le feuillage, en particulier celle des hydrocarbures dissolubles.

En résumant ce qui vient d'être dit on peut indiquer le rôle de la matière organique dans le sol comme suit: La matière organique agit sur les propriétés physiques du sol arable et elle sert à régler l'influence des facteurs importants pour le développement d'une plante: la température, l'humidité et l'amenée de l'oxygène aux centres embryonaux (racines) de la plante et de l'acide carbonique à ses parties vertes.

Néanmoins des études détaillées ont montré que la fonction des composés organiques dans le sol est beaucoup plus ample en ce qui concerne les problèmes principaux de la *nutrition azotée* et surtout de la *nutrition carbonique* des plantes.

Les recherches faites dans les dernières années par plusieurs physiologues et agrochimistes ont établi que ce ne sont pas seulement les cendres qui servent à la nutrition des plantes, mais qu'il y a aussi des solutions de certaines matières organiques qui forment un élément important de cette nutrition, en fournissant du carbone actif, nécessaire aux procédés énergétiques qui s'effectuent au cours de la synthèse des albuminoïdes.

Les albuminoïdes ne peuvent se former aux dépens de l'azote contenu dans les nitrates que si ceux-ci sont réduits en ammoniaque; cette réduction se fait dans l'organisme de la plante en présence et avec concours des hydrates de carbone solubles; l'ammoniaque composée avec le glucose et puis oxydée donne naissance à l'asparagine d'où se forme, après l'élimination de l'ammoniaque, une série d'amides qui réussissent enfin à former des albuminoïdes. Ces processus exigent inévitablement la présence des hydrates de carbone libres qui, formés dans le feuillage comme produits de la photosynthèse, descendent aux racines où ils sont brûlés en participant à la formation des albuminoïdes; il est évident qu'il y a des pertes d'énergie dans ce processus, puisque les produits formés par la photosynthèse, destinés à la construction de la plante ou à leurs provisions, sont détruits dans les racines. Ces pertes peuvent être diminuées si on amène aux racines des matières organiques azotées qui peuvent être réduites en ammoniaque par des processus de fermentation n'exigeant pas de matières de construction faites par le feuillage, ou encore si on amène aux racines des matières carboniques capables de fournir les hydrocarbures libres nécessaires à la formation des albuminoïdes. On a trouvé, par suite de recherches nombreuses et prolongées, que ce sont surtout les composés humiques dont la présence dans le sol a les effets indiqués ci-dessus et qui contribuent ainsi au développement favorable des végétaux. On peut citer à cette occasion les recherches de l'Institut Forestier de l'empereur Alexandre et les travaux de MM. Breal et Risser par rapport à la nutrition des forêts et des tourbières d'où provient l'opinion que les solutions de matières humiques et des dérivés de leurs hydrolyse et oxydation ont un rôle important dans le développement des bois et des blés. Le rôle des matières humiques a été signalé aussi par les observations de M. S. Bogdanoff dont les opinions ont été confirmées par des recherches de longue durée faites par M. Vikgorst dans les régions du sud-est de la Russie, du Turkestan et de l'Oussouri.

On voit donc que les composés humiques contribuent à élever la quantité de la matière organique de la plante par une action double:

indirectement en réglant d'une manière favorable les conditions du milieu entourant la plante, ou directement en prenant part aux procédés de formation de la matière organique. Quant à ce dernier mode, il n'a pas pu être prouvé jusqu'alors si le système des racines accepte directement les solutions des matières humiques et les produits de leurs décomposition ou si l'influence de ces matières consiste seulement dans ce qu'elles épargnent à la plante, en lui apportant de l'azote sous une forme plus convenable, les pertes d'énergie inhérentes à la réduction des nitrates. Néanmoins, les résultats des recherches faites par l'auteur prouvent d'une manière évidente que la présence de matières humiques dans le sol contribue, dans certaines conditions bio-climatiques, à ce que les plantes forment des quantités plus élevées de matière organique; ceci est naturellement d'un grand intérêt, puisqu'il s'agit des plantes agricoles.

L'auteur a exécuté, avec l'aide de "Ústav pro hospodárné využití paliv" ("Institut pour l'utilisation rationnelle des combustibles"), en 1924-1928, une série d'expériences dans le but d'établir l'influence des combustibles nouveaux sur le développement des plantes agricoles. Il avait employé comme combustibles:

1. Des charbons bruns en poudre.
2. Des composés humiques, produits de charbons bruns par des méthodes spéciales.

Les expériences ont montré qu'une certaine quantité de charbon broyé (grains de 0,25 mm.), introduite dans la couche arable du sol, a produit une influence favorable au développement des plantes: les racines ont été plus riches (voir le tab. I et les photos Nos. 1, 2, 3, 4 et 5) et l'état général des plantes a été meilleur que chez les plantes de l'autre terrain. Un changement d'état chimique du sol n'a pas été établi; la quantité de sels minéraux accessibles à l'assimilation des racines est resté presque invariable. Les variations favorables qui ont été constatées consistaient en ce que la courbe de la température du sol de 24 heures a abaissé son amplitude en s'approchant mieux à une courbe moyenne idéale (voir le diagramme No. 4); l'aération du sol s'est améliorée et son pouvoir de conserver l'eau s'est élevé. Sur un terrain où on avait introduit de 10.000 à 20.000 kg. de charbon par hectare de surface, la récolte des plantes a surpassé de 54-55 pour cent celle des plantes du terrain sans charbon; pour 30.000 à 40.000 kg. par hectare, cet effet s'est un peu abaissé (tab. II.), de même que pour de petites quantités de charbon (de 10.000 à 2.500 kg. par ha.); un champ de maïs (avec sol argileux), engraissé par des quantités de 2.500 à 1.400 kg. de charbon par ha.,

a donné une récolte surpassant celle du champ normal seulement de 10 à 1,78 pour cent (tab. III.).

Ces expériences n'ont qu'une valeur d'information, ayant montré que malgré l'influence favorable du charbon son application pratique est assez difficile, vu les quantités de charbon nécessaires.

L'auteur a donc employé des charbons bruns pour la préparation des engrais artificiels dont la composition et les propriétés chimiques et physiques correspondaient à celles des matières humiques naturelles (voir le tab. IV.). Ces engrais ont été introduits dans le sol par des machines à semer ou de main. Parmi les plantes observées ont été le blé, les légumes, le tabac, la vigne et le houblon. Les conditions générales du climat, du milieu, etc., ont été les mêmes que pour des cultures normales. Les tableaux V., VI., VII., VIII. et X. indiquent les analyses d'engrais préparés de charbons et donnent les résultats obtenus. Les quantités d'engrais introduites dans 1 ha. de sol ont correspondu à des quantités de 175 à 350 kg. et de 700 kg. de charbon employé.

Pour faire comparaison entre les composés humiques artificiels et les engrais minéraux, l'auteur a fait en 1928 de nouvelles expériences où les plantes ont reçu dans les deux cas les mêmes quantités d'azote. Les vases de végétation ont été ainsi distribués: No. 1: sans engrais; No. 2: 0,3725 g. de salpêtre du Chili; No. 3: 0,6332 g. de carbo-humate No. 872 (avec 9,4551 pour cent d'azote); No. 4: 1,4155 g. de carbo-humate No. 883 (avec 4,2164 pour cent d'azote); No. 5: 0,6451 g. de superphosphate de 16,41 pour cent. De cette manière les vases No. 2, 3 et 4 ont reçu les mêmes quantités de 0,0597 g. d'azote, le vase No. 2 ayant reçu, avec le salpêtre, 0,3129 g. de ballast inactif en matières minérales et les vases Nos. 3 et 4 0,5272 g. et 1,1294 g. de substance organique sous forme de composés humiques.

Les analyses détaillées des récoltes de ces plantes ont montré que les composés humiques prennent part à la nutrition des plantes non seulement par leur azote, mais aussi par leur matières non azotiques, ce qui se fait voir du tableau IX. (à regarder le poids de la matière organique sèche des Nos. 3, 4 en comparaison avec No. 2).

Il resterait encore à établir les détails de ces évènements, p.ex. à quel degré les matières humiques servent directement à la nutrition (comme p.ex. les engrais minéraux) et à quel degré elles agissent comme stimulateurs des différents processus s'effectuant dans les plantes. Néanmoins, les résultats obtenus montrent de nouvelles et amples possibilités d'utilisation des charbons à bas pouvoir calorifique.

RÉSUMÉ

The author develops a new conception as to humic compounds and explains the functions of these materials with reference to the life of plants, from his own observations as well as from those of other investigators. The presence of these compounds in the soil, on the one hand, is conducive to favourable physical and biological conditions, and, on the other hand, these substances and their decomposition products serve also as important nutritive material for plants, this being due to their content of nitrogen and carbon compounds. Soils which contain humic compounds are characterised by an increased productivity as regards commercially important plants.

In the event that these compounds are lacking in the soil in its natural condition they can be replaced

(*a*) By the introduction of a suitable amount of brown coal dust into the arable land.

(*b*) By the introduction of artificial humic compounds possessing the physical and chemical properties of naturally occurring humus and capable of being produced from many sorts of coal. The artificial compounds are prepared in a condition suitable for rendering possible their introduction into the soil simultaneously with the usual inorganic fertilisers.

The results of experiments carried out with coal products of the type indicated are described, and it may be seen from them that the lower grades of brown coal are applicable for the production of good water-soluble organic fertilisers.

TABLEAU I.

RÉSULTATS DES ESSAIS POUR FIXER L'EFFET PRODUIT SUR LE DÉVELOPPEMENT DES PLANTES AGRICOLES LIGNITE EN POUDRE

Lignite	De la mine Hedvika
Plant à l'essai	Froment
Quantité de lignite par ha	300 q
Lignite introduit à une profondeur de	27 cm.

Numéro des tiges de la plante d'essai.	Plante du vase engraissé au lignite				Plante du vase sans fumier.			
	Hauteur de chaque tige.	Longueur des épis.	Poids de chaque tige.	Nombre de grains dans l'épi.	Hauteur de chaque tige.	Longueur des épis.	Poids de chaque tige.	Nombre de grains dans l'épi.
1	112	10	3,85	39	98	10	3,5	34
2	116	12,6	4,94	48	92	10	3,2	32
3	116,3	12,2	5,04	36	104	11,2	4,6	34
4	116,3	11,7	5	52	101	9,4	4	38
5	112	10,4	3,80	40	91	11,2	2,6	37
6	113	10,2	4	41	77	9	2	40
7	105	10	3,20	34				
8	89	9,2	2,60	—				
Valeurs moyennes	109,9	10,8	4,05	41	93,8	10,1	3,3	36

Poids total de tous les épis ...	gr. 19,45	... ... gr. 14
Poids net des grains	,, 8,6	... ... ,, 4,8
Poids de la pelure des grains ...	,, 4,2	... ... ,, 3,8

Extrait du rapport de l'auteur fait à la Section Tchèque du Conseil Agricole 1925.

Photo. 1. Photographie des plantes d'essai après la récolte.
Plante d'essai (*a*) d'un vase engraissé; (*b*) d'un vase sans fumier.

TABLEAU II.

RÉSULTATS DES ESSAIS POUR FIXER L'EFFET PRODUIT SUR LE DÉVELOPPEMENT DES PLANTES AGRICOLES PAR DU LIGNITE EN POUDRE

Lignite de la mine "Hedvika" C.S.R.
Plante à l'essai Froment
Quantité de lignite par ha. 25 q 50 q 100 q 200 q 300 q 400 q
Lignite introduit à une profondeur de 10 cm.

Quantité de lignite par parcelle	Résultats moyens des mesurages des hauteurs des tiges.					Résultats des analyses détaillées de la récolte										
	Hauteur moyenne en cm.					Hauteur totale des tiges	Hauteur totale des épis	Hauteur totale des épis et des tiges.	Nombre d'épis non développés	Nombre d'épis bien développés	Hauteur moyenne d'un épi	Nombre moyen de grains par épi	Nombre total de grains de la récolte	Leurs poids.	Le poids des grains augmente par grain	Augmentation de la récolte en pour cent
	9-V.	12-V.	18-V.	24-V.	2-VI.											
0	9	14	32	67	92	164	15	179	—	3	5	24	92	2,92	—	—
25 q	9,8	15,5	44,4	100	155	307,5	27,5	335	1	5	5,5	24	119	3,85	0,93	24,2
50 q	9	14	30,3	89	180	624	58,5	682	3	8	7,3	26	186	5,76	2,84	49,4
100 q	9	14	32	86	164	686	63	749	3	9	7	26,8	221	6,63	3,71	55,96
200 q	11	20,7	47,3	92	193	680	59	739	4	8	7,4	26,7	213	6,39	3,47	54,30
300 q	11	20,8	49	94	126	542	46	588	4	6	7,7	26,4	108	3,67	0,75	20,44
400 q	11,5	20,8	47,5	90	188	392	37	430	3	4	9,4	26,7	131	4,19	1,17	30,32

Extrait du rapport de l'auteur fait à la S. Tch. du C. Agricole 1926.

Photo 2. Plantes d'essai avant le jettement des épis.

Photo 3. Après six jours.

TABLEAU III.

RÉSULTAT DES ESSAIS POUR FIXER L'EFFET PRODUIT SUR LE DÉVELOPPEMENT DES PLANTES AGRICOLES PAR DU LIGNITE EN POUDRE: FRUIT D'ESSAI: MAIS; QUANTITÉ DE LIGNITE PAR HA.: 14 q; LIGNITE DE LA MINE "HEDVIKA" C.S.R.

Sortes de maïs.	14-fumage 0. sans fumier	Résultats moyens des mesurages des hauteurs des tiges						Résultats d'analyse de la récolte						Augmentation en pour cent sur les terrains engraissés
		15-V	5-VI	9-VII	16-VII	24-VII	10-X	Différence moyenne dans les phases	Poids tot. des tiges des plantes d'essai		Hauteur moyenne d'un épi	Poids moyen d'un épi	Poids total de la écolte des épis.	Poids absolu de la récolte des épis	Augmentation sur les terrains engraissés	
Nord Dakota ..	14 q	6,3	55	68	94	108			2.730		18,6	142,2	3.085	3.085		
	0	6,3	39	67	89	103		+5,24	2.620		17,1	126	2.775	2.775	+310	10,05
Quebec	14 q	5,3	52	84	131	136			2.660		17,7	142	4.550	4.118		
	0	5,5	47	82	124	129		+4,2	2.480		17	128	3.346	3.723	+395	9,6
Gehu	14 q	4	52	83	111	112			2.780		17	128	2.659	2.382		
	0	4,2	44	76	105	111		+4,56	3.230		17,8	144	2.450	2.736	—354	
	14 q	4	52	96	168	170	174		3.660		16.3	145	3.780	3.552		
	0	4	49	91	146	156	161	+9,66	3.100		16	138	3.175	3.338	+214	6,03
Gold Glov ..	14 q	4,7	54	103	145	163	172		4.030		18,4	159	4.145	3.975		
	0	4,5	46	88	128	150	157	+10,55	3.390		17,5	145	3.485	3.625	+350	8,81
Cekler	14 q	5,7	45	105	146	197	274		1.320							
	0	5,4	43	89	133	187	261	+9,20	1.200							
Braunkaunte ..	14 q	7,2	53	119	169	178	187		4.300		16	185,6	5.012	4.825		
	0	7,2	48	115	160	162	176	+7,1	4.200		15,6	168	4.056	4.720	+105	2.18
Smatnos fl. ..	14 q	4,6	57	76	130	184	198		6.750		21,7	206	3.307	3.307		
	0	4,8	52	78	131	174	188	+3,5	6.500		20,1	101	3.060	3.060	+247	7,47
King Philipp ..	14 q	5	48	69	114	152	161		6.000		23	225	4.060	3.825		
	0	5	46	80	134	166	170	—8,51	6.350		23	221	3.540	3.757	+ 68	1,78

Extrait du rapport de l'auteur à la S. Tch. du C. Agricole 1925.

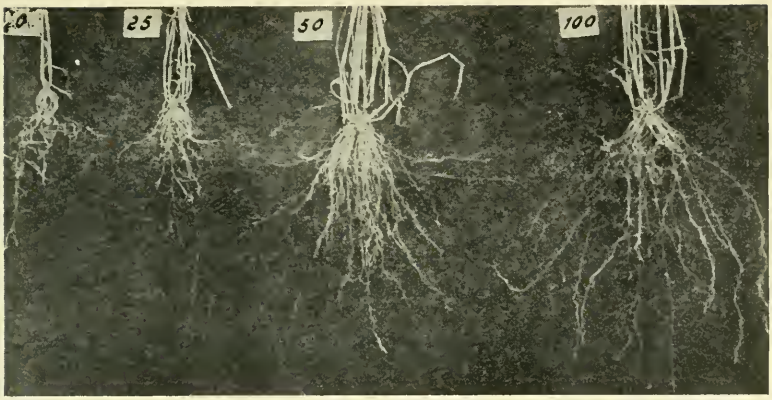


Photo 4. Vue sur les racines de chacun des vases engraissés (100 q, 50 q, 25 q.) et sur la racine du vase sans fumier.

Photo 5. Image exemplaire d'un essai sur froment en champ préparé au lignite en poudre d'une quantité de 25 q, 50 q, 100 q, et en champ sans fumier.

TABLEAU IV.

Tableau des analyses élémentaires des étoffes humiques naturelles d'origine varié et des analyses élémentaires des étoffes humiques artificielles, dont nous nous sommes servis tant pour les essais végétaux aux laboratoires que pour ceux aux champs dans une mésure plus grande.

	Etoffes humiques d'origine naturel				Et. hum. artificielles		
	211	212	213	214	883	8132	872
C	61,68	60,44	59,95	58,34	50,78	50,76	50,08
H	5,59	5,04	5,36	4,39	5,32	5,53	4,49
N	1,60	1,27	1,25	2,26	4,21	6,09	9,45
S	0,89	0,38	0,74	0,07	0,26	0,18	0,15
O	30,22	32,87	32,50	34,92	36,92	37,46	35,87

TABLEAU V.

RÉSULTATS DES INVESTIGATIONS COMPARANTS POUR FIXER L'EFFET PRODUIT SUR LE DÉVELOPPEMENT DES PLANTES PAR LES ETOFFES ARTIFICIELLES HUMIQUES

Plante d'essai: Froment
Quantité du fumier par ha. 175 kg. 350 kg. 700 kg.
Sorte des préparations Karbo Humat I-II-II-IV
Manière d introduction du fumier

Sorte et quantité du fumier par ha.	Coefficient de multiplication des tiges.	% d'augmentat.	Hauteur moyenne des tiges.	% d'augmentat.	Hauteur moyenne des épis.	% d'augmentat.	Poids total des épis		Poids moyen d'un ép.	% d'augmentat.	Poids absolu de la récolte des grains.	% d'augmentat.	% en moyenne de tous les résultats.		Augmentation effective en % de la récolte des grains sur les terrains engraissés
Sans fumier 0 ..	2,15		77,63		3,88		105		0,5049		93				
K.H.-I 175 kg. ..	2,80	23,12	85	8,68	5,75	32,83	124		0,8322	29,72	133	29,47			
,, 350 ..	2,50	38,58	86,59	10,35	5,01	22,56	135		0,7848	25,48	126	25,55	25,21		
,, 700 ..	3,15	31,75	87,35	11,16	5,34	27,35	130		0,8426	31,01	126	31,08			28,31
K.H.-II 175 ..	3,15														
,, 350 ..	2,75	21,82	90,57	14,29	5,00	22,40	125		0,7812	25,13	125	24,96			
,, 700 ..	3,50	38,53	89,56	13,33	5,19	25,25	125		0,8223	18,96	132	28,90	25,26		
K.H.-III. 175 ..	2,90	26,37	82,72	6,16	4,31	9,98	124		0,6595	11,29	106	11,50			
,, 350 ..	2,09	28,10	82,04	5,38	4,23	8,28	107		0,6948	15,82	111	15,49	13,23		
,, 700 ..	2,50	14,59	80,00	2,97	4,46	12,81	104		0,6887	15,01	110	14,72			14,99
K.H.-IV 175 ..	2,19	1,83	82,88	6,34	4,76	18,49	92		0,6344	7,81	102	8,03			
,, 350 ..	2,79	22,90	87,10	10,88	5,09	25,78	117		0,7358	20,51	118	20,50	14,28		
,, 700 ..	2,55	15,69	82,47	5,87	4,90	20,98	97		0,6870	14,87	110	14,72			
Superphosphate ..	2,37	9,29	85,08	8,76	4,18	11,18	117		0,7005	16,57	112	16,35	12,33		17,16

Extrait du rapport de l'auteur à la S. Tch. du C. Agricole 1927.

Expérience fait sur la ferme "Radlik" Dr.-Ing Hanus.

TABLEAU VI.

RÉSULTATS COMPARANTS DES INVESTIGATIONS POUR FIXER L'EFFET PRODUIT SUR LE DÉVELOPPEMENT DES PLANTES PAR LES ETOFFES ARTIFICIELLES HUMIQUES

Plante d'essai. BETTERAVE ORDINAIRE

Poids de chaque betterave des terrains d'essais

Terrain sans fumier.		Engraissé.		Engraissé.	
1.300	510	1.260	600	1.450	870
1.090	500	1.260	570	1.440	860
1.050	500	1.250	540	1.300	860
1.030	500	1.230	480	1.330	850
910	460	1.140	460	1.210	820
880	460	1.040	460	1.200	810
800	490	930	450	1.800	800
770	360	890	450	1.170	770
730	350	850	440	1.130	740
740	340	860	410	1.120	720
710	340	870	400	1.020	700
710	330	830	390	1.020	670
710	320	810	380	1.020	650
690	310	800	370	1.020	650
690	290	780	360	1.040	630
640	270	780	350	1.040	630
640	230	780	320	1.000	570
610	230	750	270	970	570
610	140	740	460	960	560
565	460	700		960	480
550		680		930	470
530		670		910	430
530		670		900	420
870		630		900	350
560		630		870	320
810		1.230			310
Poids total	27,05		31,22		43,96
Poids absolu	27,98		33,46		40,29

	Sans fumier.	Engraissé 700 kg. 1 ha.	Engraissé 1.400 kg. 1 ha.
Nombre de betteraves sur les terrains d'essai	46	45	52
Leurs poids total	27,05	31,22	43,96
Poids moyen d'une betterave ...	587,28	693,27	845,38
Poids absolu de la récolte	27,95	33,46	40,20
Récolte sur les terrains engraissés est augmentation en pour cent ...	—	15,34	30,56

Extrait du rapport de l'auteur à la S. Tch. du C. Agricole 1927a.

Photo 6. Sans fumage.

Photo 7. Engraissé par 700 kg. d'étoffes artific. humiques par ha.

Photo 8. Engraissé par 1.400 kg. d'étoffes artific. humiques par ha.

TABLEAU VII.

RÉSULTATS COMPARANTS DES INVESTIGATIONS POUR FIXER L'EFFET PRODUIT SUR LE DÉVELOPPEMENT DES PLANTES PAR LES ÉTOFFES ARTIFICIELLES HUMIQUES (KARBO HUMATS)

Plante d'essai: VIN.

Lieux d'expérience.		Vignes d'état "Beregovo."								Vignes d'état "Valtice."								Contenance de sucre v. Beregovo. en %	
Sorte de fumier.		0		K.H.-IV.		K.H.-III.		K.H.-I		K.H.-IV.		K.H.-III.		K.H.-I.		0			
	Quant. de fumier dans un buisson.			125 gr.	250 gr.	125 gr.	250 gr.	125 gr.	250	125	250	250	250	250	250			Contenance de sucre en %.	Différence.
0	Poids de la récolte.	4 6	3 5													3 3	5 6	8,5 9	18	
K.H.-IV.	Poids de la récolte.			6	8,6					5,75	8								18,6	+0,6
	Augmentation de la récolte en %.			19,34	43,03					13,40										
K.H.-III.	Poids de la récolte.					7,4	9,6					11,25	12						18,2	+0,2
	Augmentation de la récolte en %.					33,79	48,96					49,8								
K.H.-I	Poids de la récolte.							8,6	12,8					8	9				19,5	+1,5
	Augmentation de la récolte en %.							43,03	62,72					30						

Extrait du rapport de l'auteur à la S. Tch. du C. Agricole. p.a. 1927.

Essais faits sur les vignes de l'Etat de Beregovo et Valtice.

Photo. 9. IV. Engraissé par étoffes artific. humiques IV. O—Sans fumage.

Photo. 10. K.-H. III. Engraissé par étoffes artific. humiques III. O—Sans fumage.

TABLEAU VIII.

RÉSULTATS COMPARANTS DES INVESTIGATIONS POUR FIXER L'EFFET PRODUIT SUR LE DÉVELOPPEMENT DES PLANTES PAR LES ÉTOFFES ARTIFICIELLES HUMIQUES (KARBO HUMATS)

Plante d'essai: le houblon

Sorte du fumier artific. humique.				Karbo Humat I		Karbo Humat III		Karbo Humat IV	
Quantité de fumier par buisson.				125 gr.	250 gr.	125 gr.	250 gr.	125 gr.	250 gr.
Nombre des buissons sur le terrain d'essai	24	25	25	25	24	25	25	25	24
Nombre des corbeilles de houblon écru récoltées ..	12	13	13	12	14	12	12	13	13
Poids du houblon écru récolté	20,5	25	22,5	23	24,5	20	24,5	22,5	24
Poids du houblon séché récolté	5,30	6,60	6,50	6,40	6,60	6,60	6,90	6,50	6,50
		248							
Poids moyen de la récolte d'un buisson	220	264	260	256,8	270	264	276	260	270,8
Poids absolu de la récolte ...		6,20							
	5,50	6,60	6,50	6,40	6,75	6,60	6,90	6,50	6,77
La récolte des terrains engraissés est augmentée par granum				+ 200 gr.	+ 550	+ 400	+ 700	+ 300	+ 570
Pour cent d'augmentation de la récolte	—	—	—	+ 3,70	+ 8,44	+ 6,30	+ 13,84	+ 4,51	+ 8,51
Récolte moyenne par ha. ...		10,54 q		10,94 q	11,48 q	11,22 q	11,73 q	11,05 q	11,51

Extrait tiré du rapport de l'auteur à la S. Tch. du C. Agricole 1927. Essai fait sur la ferme de l'Etat "Ploskovice"

TABLEAU IX.

RÉSULTATS COMPARANTS DES INVESTIGATIONS POUR FIXER L'EFFET PRODUIT SUR LE DÉVELOPPEMENT DES PLANTES PAR DU SALPÊTRE DU CHILI, DU SUPERPHOSPHATE ET LES ÉTOFFES ARTIFICIELLES HUMIQUES (K. H.)

Expérimenté sur du froment

Numéros des vases de végétations.	Sortes des fumiers.	Poids du sol dans le vase.	Poids des fumiers utilisés.	Mis dans le sol avec le fumier.				Resultats d'analyse de la récolte.				Augmentation de la matière organique des plantes engraissées.	Différence de l'augment de matière sèche dans les vases 3, 4 et 2.	Différence de l'augment de de matière sèche dans les vases 3, 4, 2 et 5.	Augmentation totale de la récolte.
				Azote.	Ballast.	L'acide phosphor.	Matières humiques.	Quantité totale des fruits récoltés.	Poids total de matière sèche organique	Poids d'une tige.	Poids absolu de matière sèche organ. de la récolte.				
2	Salpt. du Chili	6,847	0,3725	0,0597	0,3128			20	7,7200	0,3860	7,7200	0,67		0,47	+9,503
3	K.H. 872	6,972	0,6332	0,0596	0,0453		0,5283	20	7,9200	0,3960	7,9200	0,87	0,20	0,67	+12,340
4	K.H. 883	6,711	1,4155	0,0597	0,2264		1,1294	19	7,9800	0,4200	8,4000	1,35	0,68	1,15	+19,148
5	Superphosphate	6,700	0,6450		0,5418	0,1032		20	7,2500	0,3620	7,2500	0,20			+2,836
1	Sans fumier	6,972						20	7,0500	0,3570	7,0500				

TABLEAU X.

RÉSUMÉ DES RÉSULTATS DES EXPÉRIENCES VÉGÉTALES FAITES POUR CONSTATER L'EFFET DES PRÉPARATIONS ARTIFICIELLES HUMIQUES (KARBO-HUMATS) SUR LE DÉVELOPPEMENT DES PLANTES AGRICOLES

Les résultats sont exprimés en pour cent de l'augmentation de la récolte des terrains engraissés par des préparations artificielles humiques et des terrains sans elles.

p.a. 1927.

Sorte des prép. artif. humiques.	I.				II.				III.				IV.				V.				Fumiers minéraux.			
Quantité de fumier par ha.	350 kg.		700 kg.		350 kg.		700 kg.		350		700		350		700		350		700		Superph. et sulf. ammonium	Superphosphate.	Kaïnite.	Salpêtre du Chili.
Froment ..	25,25		31,01		24,9		28,9		15,4		14,7		20,5		14,7						16,25			
Orge	26,25		26,5						8,5		11,8											14,3	16,3	
Betterave ord. et sucre	16,9 3,8		29 16,5		7,9 23,4		10,1 34		15,9 14,1		21,9 15,3											19 25,1		14,8
Salade				16								9				3				1				
Chou																28				28				
Chou-fleur ..												—3				31				37,1				
Chou-rave ..				—26								10				30,9				26,4				
Chou				6								—2				7,6				3,7				
Chou de Bruxelles ..				8								5,6				24,5				16,4				
Célerie				29,6								28,7				37,6				27,5				
Tomates ..				56,4								60,4				51,4				63,1				
Carottes				5,6								7,4				22,4				15				
Le hublon ..		3,7	8,4							6,3	13,8			4,5	8,3									
Vin		30 43	61,7							49,8 33,7	48,9			13,40 19,3	43,6									

METHODS OF BURNING DUTCH EAST INDIAN COALS

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Paper No. A8

CONTENTS

OCCURRENCE, AND STATISTICS OF CONSUMPTION—PROPERTIES—GRADING—FIRING BY HAND ON BOARD SHIP—IN LOCOMOTIVES—IN STATIONARY BOILERS—MECHANICAL FIRING—SPRINKLERS—TRAVELLING GRATE—UNDERFEED GRATE—SPECIAL METHODS OF FIRING FINES—BRIQUETTES—PULVERISED FUEL

ZUSAMMENFASSUNG

GENERAL REMARKS

Occurrence

Coal is found in all the larger islands of the Dutch East Indian Archipelago. Although trustworthy data as regards the available coal supply are lacking, a total quantity of 5,000 to 6,000 million metric tons has been roughly estimated, of which about 3,000 million tons must be allocated to Sumatra, and about 1,000 million tons each to Borneo and Celebes. Java, although not devoid of this mineral, has no coal areas of practical importance.

As shown on the accompanying map (Fig. 1) the most important coal measures worked at present are the Ombilin governmental coalfields, situated at Sawah-Loento in the Padang highlands, Residency of Sumatra's west coast; the Boekitasem governmental colliery of the Lematang coalfields at Tandjoeng-Enim in the Residency of Palembang; the Poeloe Laoet governmental coalfield situated on the island bearing the same name, lying off the south-east coast of Borneo; and the various coal areas scattered along the east coast of Borneo worked by private companies, given in Table I.

Coal Raised

The amount of coal raised during the year 1927 at the various collieries is given in round figures in Table I. Including native workings the total amount of coal raised in the Dutch East Indian Archipelago exceeded one and a half million tons.[1]

Home Consumption

According to the latest returns, the annual consumption of coal slightly exceeds the production. It amounts to 1,600,000 tons, of

Fig. 1.

which total 910,000 has to be apportioned to shipping, 360,000 tons to railroads, 28,000 to sugar mills, 122,000 to central electric stations and the remaining 180,000 tons to various industrial purposes.

DUTCH EAST INDIAN COAL AS FUEL

Properties

Although the characteristics of this mineral are by now sufficiently well known, it may be useful to repeat them here in order to render

[1] Accurate figures and complete list of collieries and coal mining concessions are given in the "Jaarboek v.h. Mijnwezen in Nederlandsch Indië" (Annual of the Bureau of Mines of the Dutch Indies).

this paper self-contained. Generally speaking, Dutch East Indian coals may be called gaseous, and are of Eocene age. Their colour is pitch black; when freshly mined they are hard and break with a conchoidal fracture. In the author's paper called "Fuel Power in the Dutch East Indies," submitted to the First World Power Conference (1924), the following further particulars were given:

"With the exception of the Boekit Asam variety, which owing to volcanic influences has in parts been prematurely transformed and enriched, the Dutch East Indian coal has, generally speaking, the following properties:—

TABLE I.

LIST OF PRINCIPAL COLLIERIES

No.	Name of Colliery	Locality	Owner	Net annual production in metric tons	Coaling station
1	Ombilin Colliery	Sawah Loento, Sumatra's West-coast	Government	500,000	Emmahaven
2	Boekitasem Colliery ..	Tandjoeng-Enim Residency, Palembang South Sumatra	,,	300,000	Kertapati (Palembang)
3	Poeloe Laoet Colliery ..	Island Poeloe, Laoet Residency, S.E. Borneo	,,	140,000	Stagen
4	Rantau Pandjang ..	Parapatan, East Borneo	Royal Packet Navigation Co.	200,000	Telok Bajoer
5	Goenoeng Koepang ..	Martapoera, South Borneo	South Borneo Mining Co.	20,000	—
6	Goenoeng Batoe Besar ..	Pamoekan Bay, East Borneo	G.B.B. Mining and Trading Co. (Malayan Collieries)	120,000*	—
7	Oost Borneo Maatschappij	Samarinda, East Borneo	East Borneo Co.	200,000	—
8	West Koetei Coalfield ..	Koetei, East Borneo	Native owned	20,000	—
			Total	1,500,000	

* This figure is estimated, as accurate returns are not yet to hand.

"It is non-baking, non-coking, long flaming, highly gaseous, very friable and moist.

"A comparison of the approximate analyses with that of South Wales coal discloses the fact that some varieties (Ombilin coal) contain three times as much volatiles and about six to ten times as much water. That difficulties would be experienced in burning this fuel in a furnace designed for European coal was at first

overlooked, but soon recognised. The calorific value and approximate analysis of the three most prevalent varieties are as follows:—

TABLE II.

Origin	Ombilin (Sumatra)	Poeloe Laoet (Borneo)	Boekit Asam (Sumatra)	
Variety	Lumps	Stagen steam nuts	Bituminous nuts	Anthracite nuts
Calorific value in cal. per Kg. ...	7·200	6·800	7·500	8·500
	Per cent.	Per cent.	Per cent.	Per cent.
Fixed carbon ...	56	48	55	94·4
Volatiles	34	39	38·5	3·8
Moisture	8	5·5	6	1
Ash	2	7·5	0·5	0·8
Sulphur	0·5	1	0·4	0·5

The ultimate analysis of pure coal of the above named varieties is given in Table III.

TABLE III.

Origin	Ombilin (Sumatra)	Poeloe Laoet (Borneo)	Boekit Asam Sumatra	
			Bituminous nuts	Anthracite nuts
	Per cent.	Per cent.	Per cent.	Per cent.
Carbon	79·6	76·7	74·7	92·0
Hydrogen	5·6	7·3	6·25	3·5
Oxygen	12·6	15·0	17·5	4·0
Nitrogen	1·7	15·0	1·10	4·0
Sulphur	0·5	1·0	0·4	0·5

"The serious drawback of Dutch East Indian coal is its softness. This causes a disproportionately large percentage of fines; it further necessitates careful handling of the coal during transport, and calls for specially-designed furnaces to burn it efficiently."

GRADING

The coal is marketed in three sizes:

(*a*) lumps, above 30 mm.

(*b*) nuts, from 10 to 30 mm.

(*c*) fines—or smalls beneath 10 mm.

A fourth quality, called mixed smalls, is formed by mixing nuts with fines.

FIRING OF LUMPS

The above grading is no arbitrary one, but is naturally the outcome of practical considerations. It is in the first place due to the fact

that lump coal is exclusively used on ocean-going steamers where hand firing on fire-bar grates with large air spacings is still in vogue. The obvious truth of the assertion that for distant oversea traffic only high-grade fuel can yield economical results has been fully recognised long ago, and is rigorously put into practice by shipping firms.

Firing of Nuts

For inter-insular shipping and local railroad traffic, as also stationary boilers with hand firing, nuts have proved a suitable fuel.

Mixed nuts and fines are not to be recommended for the ordinary fire-bar grate on account of the large "grate losses," but they yield excellent results on mechanically-operated grates with artificial draught.

Firing of Fines

As regards the firing of "fines," great difficulties were experienced in burning this "waste product" when applying the usual time-honoured methods, although some measure of success was obtained with hand firing on so-called Küdlitz fire grates (consisting of massive plates with numerous tapering holes for the air admission), and when applying forced draught. Even mechanical stoking gave indifferent results, so that with this material more radical measures had to be taken, and firing of this combustible in the form of pulverised fuel and briquettes had to be resorted to. Both methods have proved eminently satisfactory, as may be gathered from the more detailed description which follows.

METHODS OF BURNING DUTCH EAST INDIAN COALS

General Principles

Before considering in detail the various modes of firing which have now found general application in this country, it may be useful to restate elementary principles underlying the combustion process of bituminous coal. The fact that the fuel we are dealing with besides being highly gaseous is also non-baking, must not be lost sight of. For the complete combustion of coal a fixed quantity of air is necessary. The way in which the air is admitted to the fuel depends entirely upon the character of this fuel.

With the gassy coal in question, where the volatiles are liberated before ignition takes place, the combustion process is of a complex nature; the solids only are burnt on the grate, and the liberated gases in the furnace or combustion chamber beyond. It follows

that the air will partly have to be admitted into the ashpit under the grate, and partly be let in above the grate to burn the gases.

To promote the combustion of these hydrocarbons the combustion chamber should be liberally dimensioned, and the air should be pre-heated to accelerate the ignition process. The coal, being non-baking, precludes the application of a too heavy draught and concomitantly calls for a thicker fuel bed than would at first sight be deemed compatible with its volatile nature.

Firing by Hand

The author is of the opinion that one efficient way of hand-firing Dutch East Indian coals would be to adopt James Watt's abandoned "coking system" of firing, whereby the green coal was piled on the dead plate, thereby serving as fire door. The great advantage of adopting this method with gaseous coal will be readily understood The gases evolved on the dead plate becoming intimately mixed with air, travel over the whole length of the incandescent fire and cannot fail to become ignited and consumed in the spacious flue beyond. With careful stoking an almost continuous and uniform admittance of air and coal could be attained. Neither of these desiderata are present with the modern hand-fired boiler, as the charge is applied very intermittently, and each time the fire door is opened to replenish the fire a rush of cold air is let into the furnace, which, besides cooling down the flue and other parts of the boiler, will give rise to an excess of air which will temporarily have a disturbing effect upon the combustion process. By the application of frequent small charges and the substitution of natural draught by artificial balanced draught, this evil may be minimised, but never entirely obviated.

Hand Firing on Board Ship

Hand firing (by natives) is still largely practised on board the steamers plying in Dutch East Indian waters.[1] All ships built prior to 1925 were equipped with the ordinary Scottish marine boiler, designed for European coals and European attendance. Practical experience all over the world has shown that these boilers stand up to their work when fired with coal with volatiles not exceeding 20 per cent., and when attended by trained firemen of robust physique. For Dutch East Indian coals with 35 per cent. to 40 per cent. of volatile contents, and when attended by native

[1] For an exhaustive treatment of this subject see Mr. Bakker's paper (in Section J) entitled "The Combustion of Tertiary Coal on Ships of the Royal Dutch Packet Navigation Company in the Indian Archipelago."

or other labour of inferior physique, they at first gave serious trouble; red-hot chimneys and choked-up fire tubes were of frequent occurrence. However, all difficulties were in time overcome, and the practical as well as scientific way in which the firing problem of the Scottish boiler has been solved, resulted in considerable financial saving. The results were obtained in the first place by paying minute attention to the air regulation, *i.e.*, accurately fixing the proper ratio of the primary to the secondary air, and in the second place by decreasing the length of the grate, thereby facilitating the task of the native fireman and enabling him to cover the grate evenly and avoid bare patches.

A third improvement was effected by increasing the height of the fire bridge in such a manner as to leave only a narrow annular-shaped passage for the flue gases between the firebridge and the roof of the flue, thereby forcing these gases to spread out and travel over the red-hot firebridge in the form of a thin sheet. History repeats itself; the difficulties stated above were experienced by British engineers a century ago, and a glance at the numerous patents taken out at that time show that the remedies suggested to cure the evil were in principle the same as those applied now.

As may be gathered, the firing of Dutch East Indian coal in Scottish marine boilers has now been raised to a fine art. The saving in fuel obtained by paying close attention to the points enumerated above is clearly demonstrated in the results given below of comparative tests taken on board of one of the vessels of the Royal Packet Navigation Co.

TABLE IV.

Date of trial	November, 1924		November, 1925
Name of vessel	Duymaer van Twist		
Registered tons	1,030		
I.H.P. of engine	1,373	...	1,358
Boiler pressure in lb. per sq. in.	160	...	160
Fan pressure in in.	1	...	$\frac{5}{8}$ in.
Air draught above fire	$\frac{1}{8}$ in.	...	$\frac{1}{16}$ in.
,, ,, under grate	$\frac{1}{2}$ in.	...	$\frac{1}{4}$ in.
Fire bridge construction	usual	...	semi-circular
Surface of grate expressed in percentage of total available area	$\pm$66 per cent.		$\pm$75 per cent.
Surface grate in square metres	$1,10 \times 0,95$	...	$1,25 \times 0,9$
Speed in miles per hour	11·5	...	11·9
Draught of ship in dM. fore	46½	...	36
Draught of ship in dM. aft	47½	...	45
Coal consumption—			
(*a*) per P.K. hour in Kg.	0·96 Kg.	...	0·76 Kg.
(*b*) per geogr. mile in tons	0·51 ton	...	0·345 ton

HAND FIRING IN LOCOMOTIVE BOILERS

Although one quarter of a million tons of Dutch East Indian coal is still burnt annually in locomotives, it needs no expert knowledge

to find out that for a locomotive with its cramped boiler construction, its vibrating grate and at times abnormally high draught, Dutch East Indian coal is no ideal fuel. Not only is there no adequate provision made for burning the gases, but much small coal finds its way unconsumed to the ashpit and through the chimney. For heavy traction and express service an excellent substitute has been found in briquetted coal.

Hand Firing in Stationary Boilers

In Lancashire or other similarly constructed boilers with long narrow furnaces, hand stoking may be adopted with some measure of success; in water-tube boilers the unfavourable design almost precludes satisfactory working. If we consider the much prevalent so-called W.I.F. type with natural draught, slightly inclined water tubes, and ordinary fire-bar grate, immediately above which the water tubes are situated, we find that the liberated gases rise almost vertically above the fire and are cooled down by striking the cold water tubes before ignition has taken place, thus escaping unconsumed through the chimney. Increasing the size of the combustion chamber, by increasing the distance between the grate and the tubes, has only brought partial relief, on account of the difficulty experienced in introducing secondary air above the fire in such a manner as to obtain a thorough well mixed and ignitable gas.

Mechanical Stoking

Mechanical stoking had to be resorted to in these lands, as in other countries, to burn small coal in an efficient manner. With rare exceptions, experience has only been gained with water-tube boilers, so that the following remarks only hold good for this type of steam raiser. Various systems have been tried, of which may be mentioned the sprinkler, the underfeed and the travelling grate.

Results with Sprinkler Grate. The sprinkler grate has now had to be abandoned. Knowing the difficulties encountered with the provision of secondary air this need cause no surprise. Experience gained with stoking apparatus within the last few years has forced us to readjust our views somewhat, and the unanimous opinion held by experts to-day is that with the gassy fuel in question only stokers constructed on the coking principle will yield satisfactory results.

Results with Travelling Grate. The travelling grate stoker is largely in use in central stations. Especially the modern type with compartment firing, when fitted to C.T.M. boilers provided with suspended fire-brick arch, and when operated with combined forced

and suction draught has given excellent results, as may be gathered from the following particulars abstracted from the officially conducted boiler trials at the Taajeh Powerhouse of the Ombilin Mines in February, 1925.

TABLE V.

Manufacturer of boilers, Stork Bros.
Type, C.T.M. Babcock and Wilcox.
Heating surface (*a*) of boiler, 615 M²
,, ,, (*b*) of superheater, 220 M²
,, ,, (*c*) of economiser, 371 M²
Grate type, travelling droplink.
Draught, combined forced and suction.
Steam pressure, 13·5 atm.
Steam temperature, ±360°C. including ±165°C. of superheat.

Trial No.	I.	II.
Fuel analyses—	Ombilin shale.	Ombilin smalls.
	0—30 mm.	0—30 mm.
Fixed carbon	39·60 per cent.	49·20 per cent.
Volatiles	33·14 ,,	38·90 ,,
Water	7·86 ,,	7·50 ,,
Ash	19·40 ,,	4·40 ,,
Calorific value in cal.	5,697	7,121
Results—		
Steam raised per hour	16,052 Kg.	15,841 Kg.
Steam raised per hour per M² heating surface	26·1	25·8
Evaporation, *i.e.*, steam + fuel	5·54 Kg.	7·44 Kg.
Fuel burned in Kg. per hour per M² grate surface	138	101
Efficiency of boilers with superheater and economiser	74·77 per cent.	78·92 per cent.
Excess air	38 ,,	40 ,,

Results with Underfeed Stokers. In this connection it may be of interest to mention that underfeed stokers were tried with Ombilin fines by the author as far back as 1918. For this purpose an existing Steinmüller water-tube boiler was equipped with an E type underfeed stoker. As may be gathered from the figures given in Table VI., the results as regards increased duty and efficiency were very encouraging.

The difficulties experienced at the Sawah Loento Powerhouse when firing small coal repeated themselves at the Telok Bajoer central station of the Royal Steam Packet Navigation Co. In this case also the installation of an underfeed stoker brought double relief, for not only did it enable this company to dispose of its inferior coal, but a net gain in efficiency of about 9 per cent. could be registered in favour of the mechanical device, as shown in Table VII. The similarity of some of the results obtained at Sawah Loento in 1918 and at Telok Bajoer in 1926 is indeed very striking. The question, which of the two types of stokers, underfeed or travelling grate, is to be given the preference for Dutch East Indian

small coal is not easily answered, as working results from a modern boiler installation equipped with underfeed stokers are not available. Notwithstanding this absence of comparative figures, the author favours the underfeed type, which, according to his opinion, possesses all the essential features to ensure success with the gassy non-baking fuel in question. This opinion is shared by the engineering staff of the Royal Packet Navigation Co., who are fitting out their new ships with water-tube boilers equipped with underfeed stokers.

TABLE VI.

COMPARISON BETWEEN HAND FIRING AND MECHANICAL FIRING.

Locality	Power House at Sawah Loento.	
Date	November, 1920	December, 1918
Type of boiler	Steinmüller water tube	Steinmüller water tube
Mode of firing	By hand	Mechanically
Type of grate	Küdlitz plates	Underfeed, type E
Draught	Combined natural with forced by steam jets	Combined natural with forced by fan
Heating surface of boiler in M^2	242	242
Heating surface of superheater in M^2	80	80
Grate surface, in M^2 ...	4·4	6·4
Fuel	Ombilin mixed fines 30 per cent. from 10 to 30 mm., 70 per cent. less than 10 mm.	Ombilin mixed fines 30 per cent. from 10 to 30 mm., 70 per cent. less than 10 mm.
Approximate analysis of fuel—		
Fixed carbon	49·2	45·7
Volatiles	31·4	35·8
Ash	10·1	10·3
Moisture	9·3	8·2
Calorific lower value ...	5,720	5,580
Evaporation per hour in Kg.	4,480	4,715
Evaporation per hour in Kg. per M^2 heating surface ...	18·4	19·5
Evaporation per Kg. of fuel	5·35	5·86
Fuel burnt per hour per M^2 grate surface	190	125
Overall efficiency of boiler and superheater, per cent.	66·5	72

TABLE VII.

COMPARISON BETWEEN HAND FIRING AND MECHANICAL FIRING

Locality	Power House at Teloek Bajoer.	
Date	May, 1926	July, 1926
Type of boiler	B + W — W.I.F.	B + W — W.I.F.
Mode of firing	By hand	Mechanical
Type of grate	Ordinary bar grate	Underfeed type E
Draught	Suction	Combined suction and forced
Heating surface of boiler in M^2	146	146
Heating surface of superheater in M^2	41	41
Grate surface in M^2	2·69	2·97

Fuel	Rantau Pandjang lumps (above 28 mm.)	Rantau Pandjang smalls (0–9 mm.)
Approx. analyses of fuels—		
Fixed carbon	49·10	43·85
Volatiles	34·78	31·74
Ash	4·40	11·01
Moisture	11·72	13·40
Calorific lower value	5,993	5,622
Evaporation per hour in Kg.	2,272	2,143
Evaporation per hour in Kg. per M^2 heating surface	15·6	14·5
Evaporation per Kg. of fuel	5·54	5·83
Fuel burnt per hour and per M^2 grate surface	152	124·5
Overall efficiency of boiler and superheater, per cent.	62·86	72

Special Methods of Firing Fines

As already mentioned, neither hand firing nor mechanical firing gave satisfactory results with "fines," so that to dispose of this material to advantage recourse to other firing methods had to be made.

Briquettes. If we again turn to the author's paper, "Fuel Power in the Dutch East Indies," we find the following remarks bearing on this subject:

"After many experiments with indifferent success a thoroughly satisfactory, hard, serviceable briquette, manufactured from Boekit Asam and Ombilin fines with 6 per cent. pitch as binding material, was placed on the market.

"Firing trials in marine and locomotive boilers gave excellent results. The verdict of the Royal Dutch Navy, after exhaustive trials, was: 'Firing qualities of Boekit Asam briquette up to Cardiff steam coal standard.' "

During the year 1927, the briquette factory turned out 115,000 tons of briquettes, the Government railways being the principal consumers. The briquette is oblong in shape, measuring 220×110×95 mm., and weighs 2·8 Kg. Its gross calorific value as supplied to the State railways lies between 7,500 and 8,200 calories.

A fairly representative approximate analysis of this fuel is:—

Fixed carbon	65	per cent.
Volatiles	25	,,
Ash	6	,,
Moisture	4	,,

For heavy traction and express service especially, the briquette has proved its worth.

The substitution of Ombilin coal by briquette fuel brought many advantages, of which the following may be mentioned:

(*a*) The evaporative capacity of the locomotive boiler could be increased by more than 20 per cent., and at the same time the draw bar pull of the locomotive could be increased right up to the limit imposed by the tractive weight, so that higher speeds of larger train formations could be adopted. (*b*) Owing to the superior qualities of the briquette a saving in weight of fuel of approximately 16 to 20 per cent. was effected.

Besides these, the following minor advantages may be mentioned: no liability to spontaneous combustion; cleanliness in handling and in firing; larger storing capacity; and absence of deterioration, as the briquette is impervious to water and retains its compact form.

Pulverised Fuel. The question of powdered fuel has occupied the minds of combustion engineers in this country for a good many years. On account of its gassy nature and the high melting point of its ash, it was thought that Dutch East Indian coal would be pre-eminently suited for firing in the form of powder. The author reiterates the opinion that the most rational and efficient way of burning Dutch East Indian coal is to fire it in the form of powder. By adopting this method of firing, the peculiar property of the coal, to disintegrate, is turned to profitable account, the crumbling process initiated by nature being completed in the pulveriser at minimum cost. It is not saying too much to suggest that powdered coal firing offers many possibilities to Dutch East Indian coal, and may be the means of greatly enhancing its value as a fuel.

An installation was ordered as far back as 1923, but owing to regrettable occurrences at home, amongst others litigation between maker and agent, the starting of the plant was much delayed, and could not take place until September, 1926. Viewed in the light of modern practice the installation presents no interesting features, and no useful purpose can be served in giving a detailed description. Suffice it to say that two existing Steinmüller water-tube boilers, each having a heating surface of 250 M^2, were detailed for these trials. For this purpose these boilers were provided with a special air-cooled combustion chamber of about 30 M^3 contents. As shown in Fig. 2, the fuel is introduced in this space by only one burner placed on the fore-top side of the said chamber.

The refractory material used for the walls consists partly of fire bricks containing 40 to 42 per cent. of Al_2O_3 having a melting point of 1,770 to 1,790°C., corresponding to Seger cone No. 35-36, and partly of firebricks containing 25 to 30 per cent. Al_2O_3 having a melting point of 1,690 to 1,730°C., or corresponding to Seger cone No. 31-33.

Each boiler has its own pulverising mill, combined with fan for effecting the mixing of primary air with the powdered coal and delivering it to the burner. The secondary air is solely dependent upon the natural draught of the chimney, and after circulating through the cooling channels in the side and front walls enters the furnace at the front side of the boiler, as shown in Fig. 2. Attention

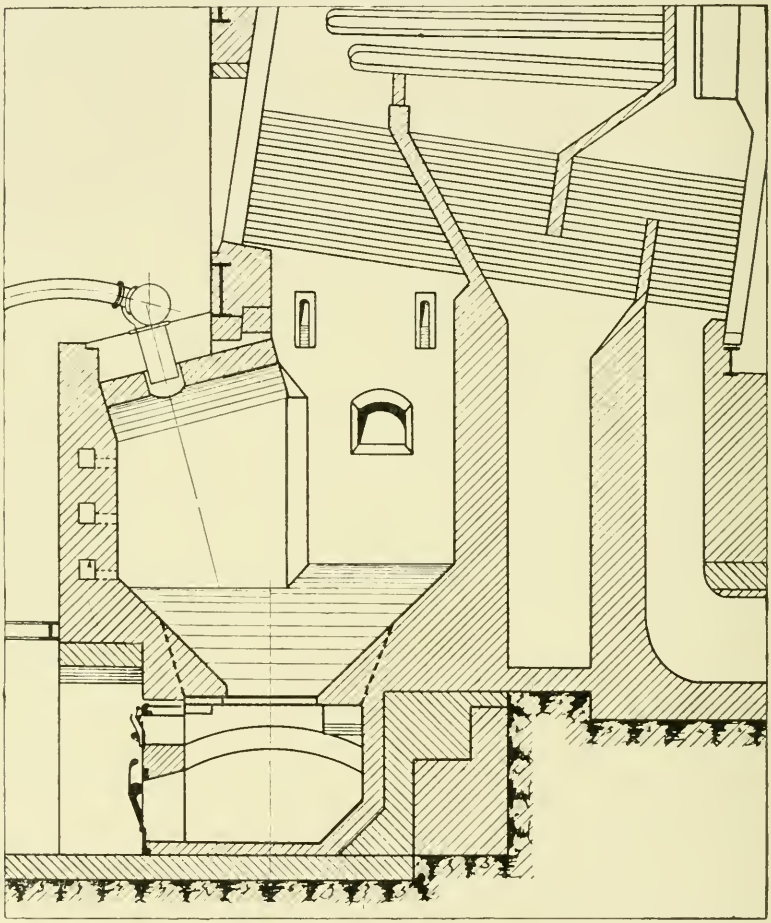

Fig. 2.

is drawn to the fact that the back wall and the tapering walls leading to the ashpit are not cooled.

The installation was bought under the following guarantees: (*a*) When using Ombilin mixed fines of usual class and analysis the evaporation can be augmented from 3,750 to 6,250 Kg., corresponding

to an increased output of ± 67 per cent. of the boiler plant. (*b*) When firing in an approved manner a CO_2 not less than 15 per cent. shall be maintained without causing damage to the combustion chamber, and the combustibles in the ashes shall not exceed 2 per cent.

The trials on both boilers together were started in October, 1926. At the initial stages of working many difficulties were encountered; especially the incipient fusing of the ash, which settled in the form of a large cone on the tapering wall beneath the burner, thereby causing frequent interruptions in the operation. A great improvement in the performance of the furnace was obtained by:

(*a*) Decreasing the speed of injection of the powdered fuel, (*b*) Augmenting the draught, thereby increasing the volume of secondary air, which in its turn acted favourably on the temperature of the walls of the combustion chamber, and (*c*) Removing the lower part of the tapering walls of the combustion chamber, thereby precluding the formation of ash cones in this locality.

As may be judged from the detailed description of the trials (Table VIII.), the ultimate results were satisfactory and in several ways exceeded expectations. In this respect attention is specially drawn to:

(*a*) The unusually high rate of evaporation with this type of boiler, which could be augmented from 15 Kg. per M^2 heating surface to 24·67 Kg. per M^2, signifying an increase in boiler capacity of 64 per cent.

(*b*) The increased efficiency of the boiler from 65 per cent. when hand fired, to 83 per cent. when powder fired, after making a liberal allowance for the power absorbed by auxiliary machinery.

(*c*) The satisfactory combustion obtained, as demonstrated by the high CO_2 contents averaging 14·7 per cent. and the almost entire absence of combustibles in the ashes.

(*d*) The very satisfactory results obtained with fines containing a large percentage of ash (Trial 1, Poeloe Laoet mixed, with 20·5 per cent. of ash).

(*e*) The fact that, contrary to results obtained elsewhere, a degree of fineness of the powdered coal corresponding to 65 per cent. (200 mesh) proved satisfactory for all practical purposes. This favourable result is no doubt due to the volatility of the coal in question.

Further advantages of powdered coal firing are the flexibility of the boiler on varying loads, and the small amount of attention required. Incidently, it may be mentioned that the costs involved

in modifying existing boilers for powdered fuel firing is prohibitive, and on this score the process is not universally to be recommended. A further disadvantage is the high cost of maintenance of the air-cooled combustion chamber, the refractory material having to be renewed after only approximately 10,000 working hours.

The conclusions arrived at, after several months' working with the plant, are that Dutch East Indian coal is an ideal fuel when fired in the form of powder, but in order to obtain the full advantage of the system it should preferably be fired in specially designed boilers.

TABLE VIII.

Manufacturer of boiler...	Werkspoor		
Type	Steinmüller watertube		
Heating surface—			
(*a*) of boiler	250 m²		
(*b*) of superheater	80 m²		
(*c*) of economiser	100 m²		
Dimensions, combustion chamber	30 m²		
Draught	natural		
Date of trials	29–6–'27	9–11–'27	10–11–'27
Duration	5 hours	6 hours	6 hours
Fuel			
Name and class	P.Laoet mixed	B.Asam mixed	Ombilin fines
Approximate analysis ...	0–30 mm.	0–30 mm.	0–15 mm.
	Per cent.	Per cent.	Per cent.
Fixed carbon	38·8	45	47·4
Volatiles	30·3	37·9	37·9
Ash	20·5	7·7	7·4
Moisture	10·4	9·4	7·3
Net calor. value, in Kg. cal.			
Weight fired during trial in Kg.	8,532	9,150	10,000
Weight fired per hour (in both boilers)	1,706	1,525	1,666
Degree of moisture of powder			
Degree of fineness, average (mesh of 200 to the linear inch), per cent.	86	84	85
Ash and Clinker			
Approximate analysis—	Per cent.	Per cent.	Per cent.
Fixed carbon	0·2	0·0	0·1
Ash	98·8	100	99·9
Weight in Kg.	828	116	274
Flue gases			
Carbon dioxide—			
(*a*) highest value per cent.	15	16	17
(*b*) mean ,, ,,	12	14·4	14·7
(*c*) lowest ,, ,,	—	12·5	14
Temperature at chimney base in °C.	152	158	170
Temperature before economiser °C.	230	242	255
Smoke density	light yellow	yellow grey	yellow to white
Suction in chimney in mm.	12 to 13	12 to 13	12 to 13
,, at boiler outlet ...	10 to 11	10	10
,, in combustion chamber	2	2	2
,, in ashpit	3	2	2
,, in cooling channels	1	1	1

Temperature in boiler house, average in °C.	33	32	32
Feed water			
Temperature before economiser, °C.	40	59	56
Temperature after economiser, °C.	90	97	100
Weight in Kg.	51,890	66,132	73,997
,, ,, per hour ...	10,378	11,022	12,333
,, ,, ,, per m^2 heating surface	20·75	22	24·67
Steam			
Pressure in Kg. per cm^2 ...	13·4	13·2	13·3
Temperature of saturated steam, °C.	195	194	195
Temperature of superheated steam, °C.	295	352	351
Various measurements			
Temperature of combustion chamber (measured at place of highest temperature) °C.	1,450 to 1,500	1,550	1,550
Temperature in ashpit, °C....	1,100	1,350	1,300

Heat account		Per cent.		Per cent.		Per cent.
Net calorific value per Kg. of fuel	5,234		6,133		6,344	
Heat used for steam raising	856	100	849	100	857	100
Heat absorbed by water in boiler	576	67·29	607	71·50	610	71·1
Heat absorbed by water in economiser	50	5·84	38	4·48	44	5·13
Heat absorbed by steam in superheater	54	6·31	84	9·89	84	9·80
Heat lost by unburnt carbon in ash	0	0·00	0	0·00	0	0·00
Heat carried away by products of combustion ...	56	6·55	50	5·89	56	6·50
Heat lost in (*a*) red hot clinker and ash, (*b*) radiation	120	14	70	8·24	63	7·39
	856	100	849	100	857	100
Deductions						
Water evaporated per hour (both boilers)	10,378		11,022		12,333	
Water evaporated per m^2 heating surface	20·75		22		24·67	
Water evaporated per Kg. of fuel as fired	6·08		7·227		7·4	
Rate of combustion per hour (both boilers) ...	1,706		1,525		1,666	
Overall efficiency of boiler with economiser and superheater, per cent. ...	79·44		85·87		86·11	
Excess of air, per cent. ...	50		34		32	

ZUSAMMENFASSUNG

Nach kurzem Überblick über Vorkommen und Verteilung niederländisch-indischer Kohlen folgen statistische Angaben über Erzeugung und Verbrauch. Der übrige Teil des Berichtes ist hauptsächlich der Besprechung der verschiedenen Methoden der Verwendung dieser Kohlen zur Erzeugung von Dampf gewidmet. Diese Kohlen, die aus dem Äozen stammen, weisen meist hochflüchtige Bestandteile auf. Sie sind äusserst spröde und verlangen besondere Behandlung. Das befriedigendste System der mechanischen Feuerung ist die Unterschub-Feuerung. Die Kohlen lassen sich unter Verwendung von Pech als Bindemittel zu Briketts von befriedigender Güte verarbeiten; als ideale Verbrennungsweise wird jedoch ihre Verbrennung als Staubbrennstoff angesehen. Der Bericht enthält 8 Tabellen, die sich grösstenteils auf Versuche mit verschiedenen Kesseltypen beziehen, bei denen niederländisch-indische Kohlen erprobt wurden.

KOREAN COALS AND THEIR UTILISATION

GOVERNMENT FUEL AND ORE DRESSING RESEARCH INSTITUTE, KOREA

PROF. M. KAMO

Paper No. A9

CONTENTS

I—KOREAN ANTHRACITE—PULVERISED FUEL FIRING—BOILER TESTS —"TAKUMA" BOILER

II—LOW-TEMPERATURE CARBONISATION OF BROWN COAL—ANALYSES OF COALS—THE "ASORBUS" CARBONISER—EXPERIMENTAL RESULTS —UTILISATION OF BROWN COAL FINES

CONCLUSION

RÉSUMÉ

INTRODUCTION

In Korea very little attention has been paid to geological surveying; consequently, the peninsula is understood to be a territory rather poorly endowed with minerals and coals, except for a few gold mines developed by foreign capital. Since the annexation of the kingdom to the Japanese Empire, great pains have been taken, directed towards the development of its natural resources, which have resulted in the discovery of several minerals, such as molybdenum, tin, iron, and some rich gold ores, and especially coal fields, the deposits of which are estimated to amount to not less than 150,000,000 tons. It is expected that a further exploration will double this figure, so that the total coal deposits in Korea will be found to amount to 40 per cent. of those in Japan proper, which are estimated at 8,000,000,000 tons.

In this territory practically no bituminous coal exists. Owing to the lack of knowledge and experience of the utilisation of these

varieties of coal, the fuel for railway traction and other industrial purposes in Korea is almost entirely coal from "Kyushu" (south-western island of Japan proper) or from the Fushun colliery in Manchuria. In either case, transportation several hundred miles by rail and water is necessary, and the amount thus imported reaches 80 per cent. of the total used, *viz.*, 700,000 to 800,000 tons annually, naturally making the fuel there extremely expensive.

The Fuel Research Institute of the Korean Government was established in 1922 for the purpose of exploring the most efficient means of utilising these native coals for industrial purposes, so as to make Korea entirely self-supporting as to fuel, and thereby lay the basis for the promotion of industry in the peninsula. This paper is intended to give a brief interim report of experimental researches conducted in the Institute for the purpose of accomplishing these objects.

I—KOREAN ANTHRACITE

Pulverised Fuel Firing

Korean anthracites are principally Palaeozoic in age, a few being Mesozoic. They are located at numerous places in the peninsula, as shown by the oblique hatching on the map (Fig. 1), the total reserve being estimated at about 800,000,000 tons. The mines actually developed at present are confined to those in the "Heijo" coalfield in the middle west, where the anthracite generally occurs in lenticular form and is produced in a fine state of division; the volatile matter contained is generally from 6 to 8 per cent., and in some instances it is as low as 3 per cent., as shown in Table I.

These facts make it imperative that the anthracite should receive special preparation in order to use it as an industrial fuel. It has long been used for briquetting or mixing with bituminous coal, but the recent development of pulverised firing has suggested the adoption of this method for the efficient utilisation of anthracite as boiler fuel.

The preliminary experiments carried out in the laboratory showed that, when pulverised, even anthracite containing only 3 per cent. of volatile matter could be completely burnt without

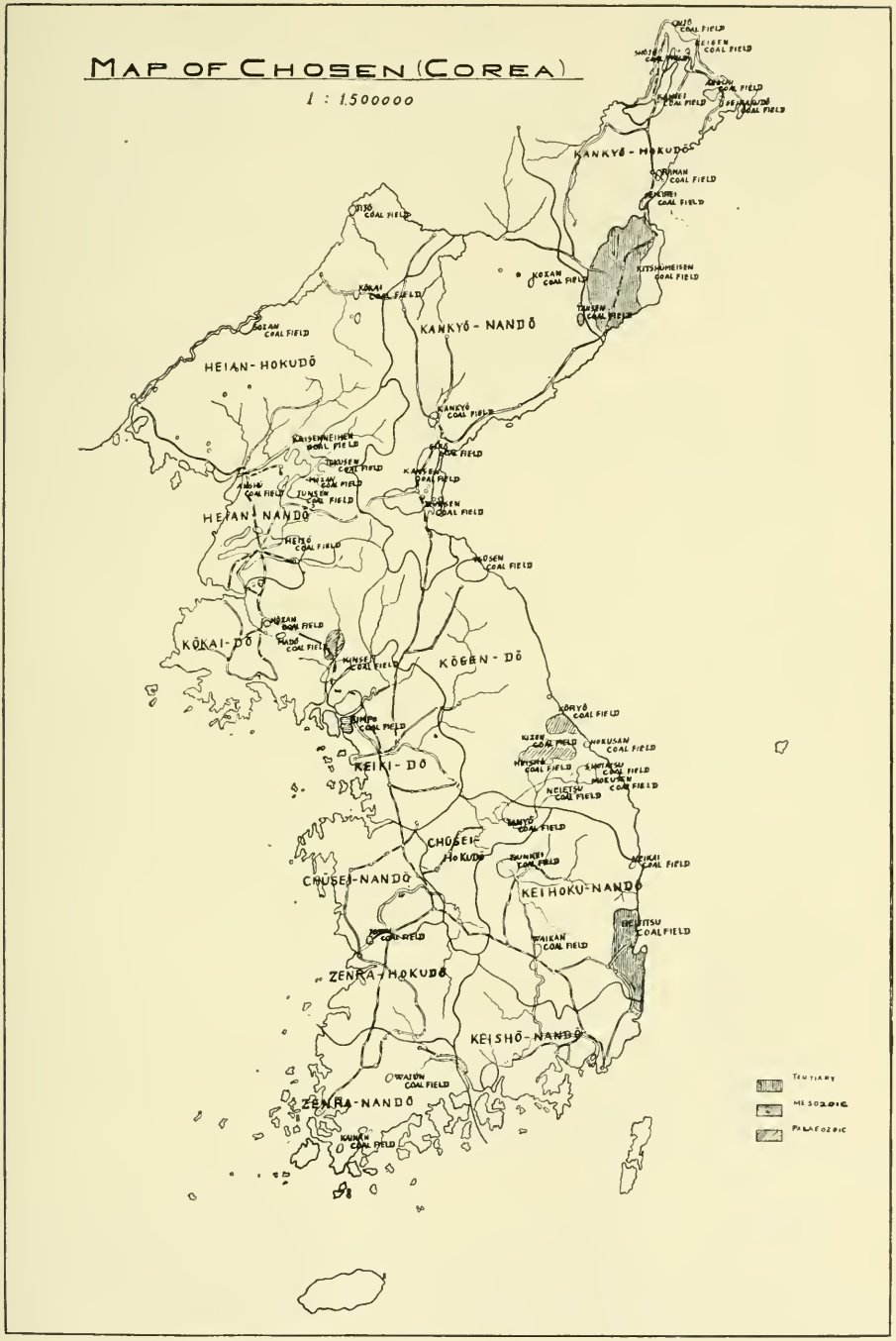
MAP OF CHOSEN (COREA)
1 : 1500000
KANKYŌ - HOKUDŌ
KANKYŌ - NANDŌ
HEIAN - HOKUDŌ
HEIAN - NANDŌ
KŌKAI - DŌ
KŌGEN - DŌ
KEIKI - DŌ
CHŪSEI - HOKUDŌ
CHŪSEI - NANDŌ
KEIHOKU - NANDŌ
ZENRA - HOKUDŌ
KEISHŌ - NANDŌ
ZENRA - NANDŌ
TERTIARY
MESOZOIC
PALAEOZOIC

Fig. 1.

any kindling mixture, so long as the moisture content was reduced to not more than 1 per cent. But at the same time, it was found that the fusing point of the ash was about 1,300°C. This fact indicates that some special precaution must be taken to reduce the furnace temperature in order to prevent ash trouble, as is generally the case with pulverised firing applied to boilers.

TABLE I

ANALYSIS OF SOME PRINCIPAL ANTHRACITES

District.	Name of Coal.	Moisture per cent.	Volatile matter per cent.	Fixed carbon per cent.	Ash per cent.	Sulphur per cent.	Calorific value. Calories.
Heian-Nan-do Prefecture.	Junsen ...	1·61	4·25	85·55	8·58	1·40	6679
	Taisei ...	0·83	9·34	86·07	3·76	0·60	7323
	Koto ...	3·25	6·50	76·32	13·93	0·60	6567
	Kosei ...	3·13	3·80	81·49	11·58	1·10	7252
	Jido ...	1·13	9·61	81·13	8·13	0·79	7685
	Taiho ...	3·63	6·55	79·57	10·25	0·74	7180
Kankyo Nan-do Pref.	Bunsen ...	4·41	3·31	87·83	4·45	0·40	8010
	Kansen ...	1·63	5·53	89·06	3·78	—	6568
Kogen Do. Pref.	Neietsu ...	1·16	7·64	65·42	25·78	0·84	4956
Keisha Hokudo Pref.	Bunkei ...	2·80	5·67	70·81	20·72	0·87	5589

With this object in view, a series of experiments on pulverised anthracite firing have been carried out with a 100 B.H.P. "Takuma" boiler, the general construction of which is shown in Fig. 2. with the anticipation that the extraordinarily quick heat-absorbing capacity which characterises this boiler might overcome the trouble caused by the fusing of ash.

Boiler Tests

Of various firing tests, which lasted for about four months, the results of two typical ones (A.—full load test; B.—half load test) are summarised below :—

TABLE II
ANALYSIS OF RAW ANTHRACITE

No. of Test.	Test No. A. per cent.	Test No. B. per cent.
Moisture	6·775	5·261
Fixed carbon	80·000	78·100
Volatile matter	6·697	8·090
Ash	12·700	13·400
Sulphur	1·161	1·050
	Calories	Calories
Calorific value	7271·0	7249·7

TABLE III
FINENESS OF PULVERISED ANTHRACITE USED IN THE TEST

Through.	Per cent.	Per cent.
200 mesh	87·1	97·5
160 mesh	94·8	98·6
100 mesh	97·0	98·9
60 mesh	99·6	99·2
Temperature of pulverised anthracite, °C. ...	60·75	52·4
Moisture in dried anthracite, per cent. ...	0·603	0·410

TABLE IV
PARTICULARS OF PULVERISED ANTHRACITE FIRING TEST

Number of Test.		Test A.	Test B.
Rate of combustion per hour in kilos.		164·6	87·72
Rate of combustion per hour in lbs.		363·0	193·5
Ditto per M^3 of combustion chamber/hour, kilos		20·76	11·066
Ditto per cu. ft. of combustion chamber/hour, lbs.		1·295	0·69
Temperature in deg. C. of Combustion gas at several parts of the Paths. (See Fig. 2).	A	1235	1402
	B	1425	1387
	C	1450	1342
	D	1227	1179·5
	E	1195	1057·3
	F	547	433·6
	G	392	367
	H	284	296·5
	K	229	210
	L	173	156
Primary air/secondary air		4·4/8	6/8
Excess air, per cent.		24	46
Evaporation/kilo of dried anthracite		8·610	7·675
Equivalent evaporation/kilo of dried anthracite		11·09	9·99
Percentage of CO_2 in flue gas		14·5	12·00
Boiler horse-power developed		118·6	55·98
Boiler efficiency, per cent.		82·20	74·29

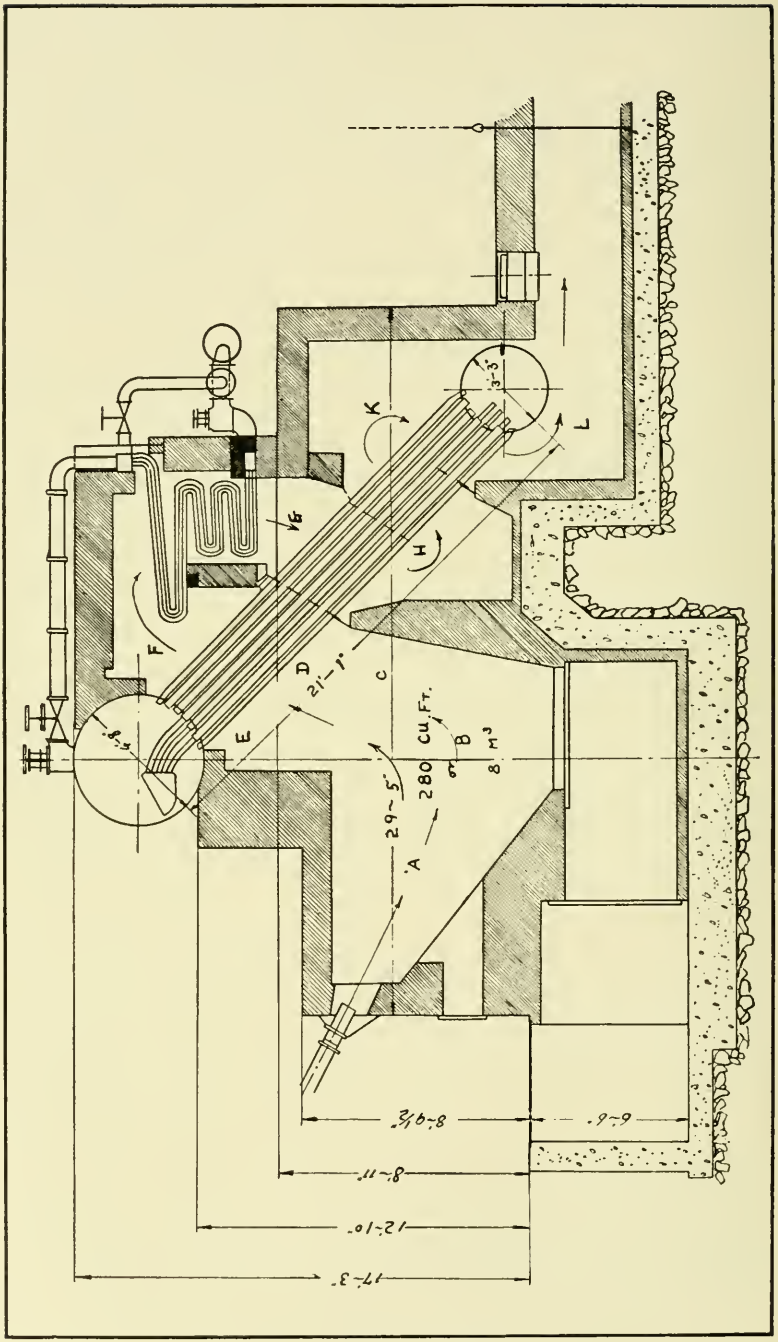

Fig. 2. "Takuma" Boiler.

The pulveriser used is of the "Aero" type, and the primary air here means the amount of air carried into the burner with the pulverised fuel. Secondary air is the air supplied through the combustion chamber door or ashpit door.

Both the tests A and B were carried on for eight or nine days continuously, and the record above given is the mean of observations during this steady firing, which lasted for 86 hours in test A, 19 hours in test B.

In these tests it has been materially proved that Korean anthracite can be burnt in a boiler most satisfactorily by pulverising. During the first twelve to twenty-four hours from the start, soft whitish ash in granular state was seen gradually covering side walls of the combustion chamber and dropping into the ash pit. This ash was found to be quite easy to remove, but after the brick walls had been heated sufficiently, although the rate of combustion was not any higher than in ordinary pulverised firing, the fused ash began to stick on the side walls, and to accumulate at the ash-pit entrance, where it solidified into a firm and hard block under the cooling action of the air, until it became practically impossible to work the boiler continuously longer than a week, unless the firing was temporarily stopped for the purpose of ash removal. The same condition prevailed even in the case of half-load test (Test B).

"Takuma" Boiler

It can, therefore, be inferred that the trouble caused by the fusion of ash is not due to the rate of combustion, but to the temperature generated by the combustion of fuel. In consequence, it was concluded that the best means of preventing ash trouble was to arrange water-circulating tubes inside the walls of combustion chamber, so as to absorb the radiant heat quickly and efficiently. This practically means an entire alteration of the construction of the boiler and combustion chamber, thereby entailing a fairly large expenditure of time and money. Consequently, as a temporary means of finding the effect of quicker absorbtion of heat from the combustion chamber, it was decided to increase the area of water-tube surface exposed to direct flame by shifting the fire-bridge backward, and, at the same time, to construct the side walls with an air-heating space, whence the heated air was introduced to the pulveriser to serve as the primary air for the combustion of fuel. This arrangement is shown in Fig 3.

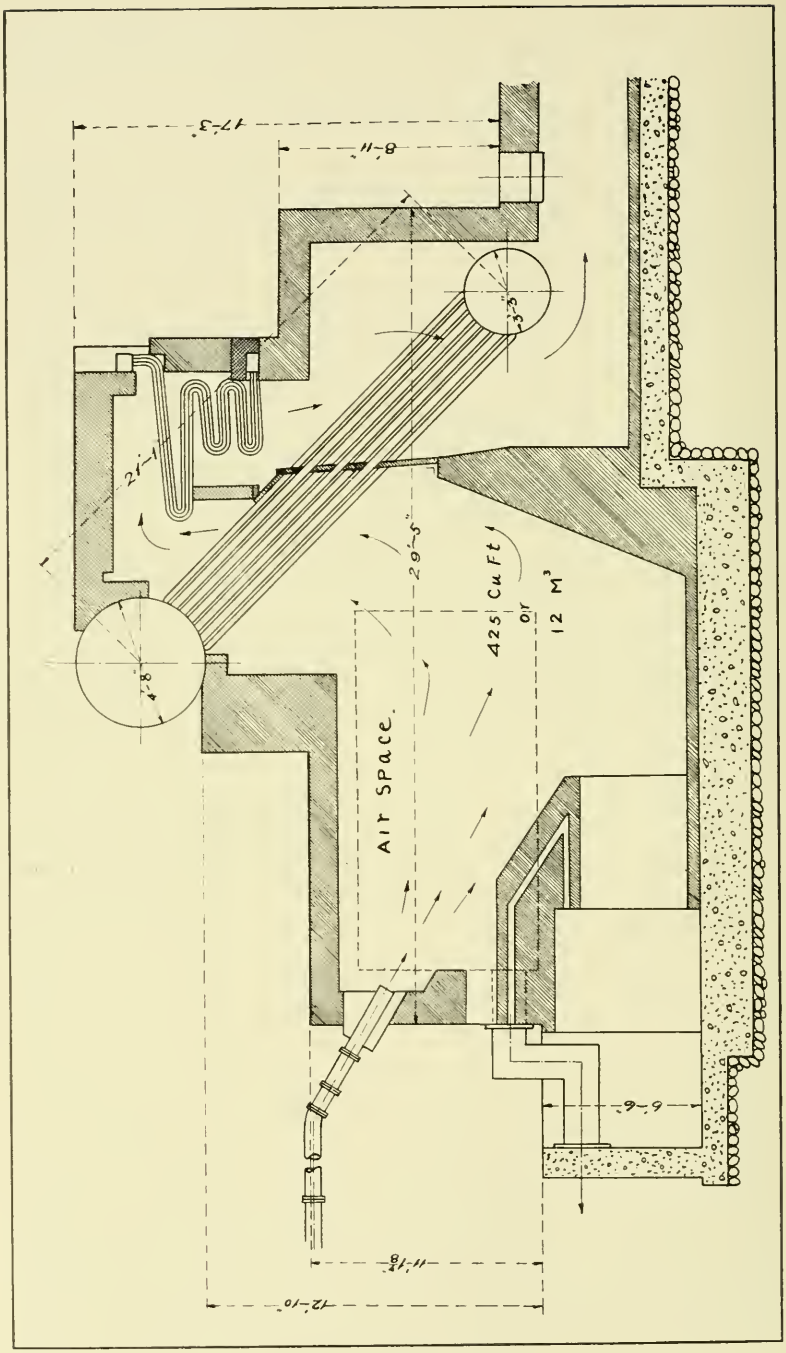

Fig. 3. "Takuma" Boiler.

This alteration resulted in increasing the volume of the combustion chamber by about 50 per cent., and eventually reducing the rate of combustion per unit volume of the chamber. In this way, the heat evolved by combustion could be absorbed more quickly by water and air, while this heated air has the effect of shortening the time required for ignition; that is to say, the length of flame (or fuel jet) between the nozzle mouth and the point of complete combustion is shortened, in addition to the diminution of the percentage of unburnt carbon. Of course, it is not maintained that this is the only remedy for the ash trouble, but to be a slight improvement on the original design as far as ash fusion is concerned.

The result of firing test with this reconstructed combustion chamber showed that the highest temperature attained was no higher than 1,300°C., and the boiler could be worked for a fortnight without stopping the firing for the purpose of ash removal. But a rather unsatisfactory path of flame and a consequent decrease of transfer of heat to water resulted in raising uselessly the temperature of the flue gas, and eventually slightly lowering the boiler efficiency.

So far, we are confident that Korean anthracite of any description can be satisfactorily burnt in boilers by pulverising, provided that the fuel is properly dried to less than 1 per cent. moisture content; and it only remains to prove that the final remedy for ash trouble is the adoption of tube-wall construction of the boiler furnace.

Fortunately, the Korean Electrical Enterprise Co., who have been burning pulverised anthracite rather unsatisfactorily for several years, have recently decided to reconstruct one of their boilers to the tube-wall system in accordance with our advice, and we trust that this improvement will prove satisfactory.

II—LOW-TEMPERATURE CARBONISATION OF BROWN COAL

Brown coal occurs in Tertiary coal measures, and is mainly located on the north-eastern border of the peninsula, but it is also found in the central district and on the south-eastern coast. These measures are shown by vertical hatching on the map (Fig. 1).

The recent survey of about one-third the area of this north-eastern coalfield disclosed a reserve of not less than 400,000,000 tons, and the total probable reserve is expected to be over 1,000,000,000 tons.

Naturally, the principal brown coal mines developed are located in this district. But the coal mined there suffers weathering to a considerable extent during storage. Within five or six weeks, 15 to 20 per cent. of coal is converted into fines, which are regarded as worthless as fuel. This characteristic property, combined with the poor transportation facilities in this district, prevents the brown coal from being widely consumed in the industrial area, and at present only about 40,000 to 50,000 tons annually are utilised for supplying the local demand. However, the high percentage of volatile matter contained in the brown coal, as shown in Table V, will produce a large yield of tar by carbonising it at low temperature, while the resulting semi-coke can be satisfactorily burnt in boilers, if pulverised.

TABLE V

ANALYSIS OF SOME OF THE PRINCIPAL BROWN COALS

District.	Name of Coal.	Moisture per cent.	Volatile matter per cent.	Fixed carbon per cent.	Ash per cent.	Sulphur per cent.	Calorific value Calories.
Kankyo Hokudo. North-Eastern Prefecture.	Onjo ...	16·32	37·92	41·47	4·29	—	5163
	Agochi ...	13·90	41·87	33·74	10·49	0·34	5536
	Kwainei	11·94	40·11	38·37	9·58	—	—
	Keirin ...	13·09	42·26	40·78	3·87	—	6150
	Hogi ...	14·17	43·18	37·20	5·45	—	5821
	Seikirei ...	17·74	43·16	30·82	8·28	—	—
	Kisshu ...	16·50	39·04	32·41	12·05	3·18	4834
	Meisen ...	3·41	24·50	66·89	5·20	0·26	7761
Kankyo Nan-do.	Kanko ...	11·65	45·40	34·23	8·72	0·45	6050
Kogen Do.	Tsuusen ...	15·80	35·18	27·12	21·90	0·45	4155
Hsian Nan do.	Anshu ...	14·77	40·56	36·59	8·08	0·21	5623
Kokai Do.	Hosan ...	17·81	32·53	42·45	7·21	2·18	5254

The "Asorbus"[1] analysis shows that any variety of this brown coal contains more than 12 per cent. of low-temperature tar.

Therefore, if a special plant, consisting of a low-temperature carbonising retort, a semi-coke burning steam power plant and a power distributing system, could be established right on the site of the mine, and the brown coal utilised by means of these equipments, it would serve to extract a fairly large amount of crude oil, and the essence of coal thus converted into electrical energy could easily be transmitted over the peninsula, avoiding the cost of the transportation of ash and water contained in the raw coal. Moreover, the undesirable effect of weathering could be entirely disregarded.

Simply from an economic point of view, it might be found preferable to utilise the coal directly for power generation, without passing it through the process of carbonisation. But in our country, home production of oil can only barely supply one-third of the total demand. Therefore, from a national point of view, we ought to utilise all possible resources for the production of oil or its substitute, the demand for which is increasing by leaps and bounds, quite independently of the amount produced in Japan.

The "Asorbus" Carboniser

For the purpose of ascertaining the actual result of the carbonisation of brown coal, a new horizontal retort of five tons capacity was installed in our laboratory, arranged to work in conjunction with the "Takuma" boiler for pulverised fuel burning.

This carboniser was designed by Dr. Naito, and is constructed as shown in Fig. 4.

First the charge is admitted through the charging hole A to the sieve S, where it is screened into finer and coarser sizes. The finer or under-sized products are carried down to the outermost threaded drum E by way of hopper B, valve V_1, and feeding screw F, while the coarser or over-sized products are introduced to the innermost threaded drum I through the hopper C, valve V_2, and the dust arrester D. The valves V_1 and V_2 are of special

[1] A special analysis developed by Dr. Naito, in which, by the aid of low-temperature distillation, the volatile matter found in technical analysis is again analysed into water (originally contained as combined water), and permanent gas tar. This is a very useful way to judge the fitness of coal for low-temperature carbonisation.

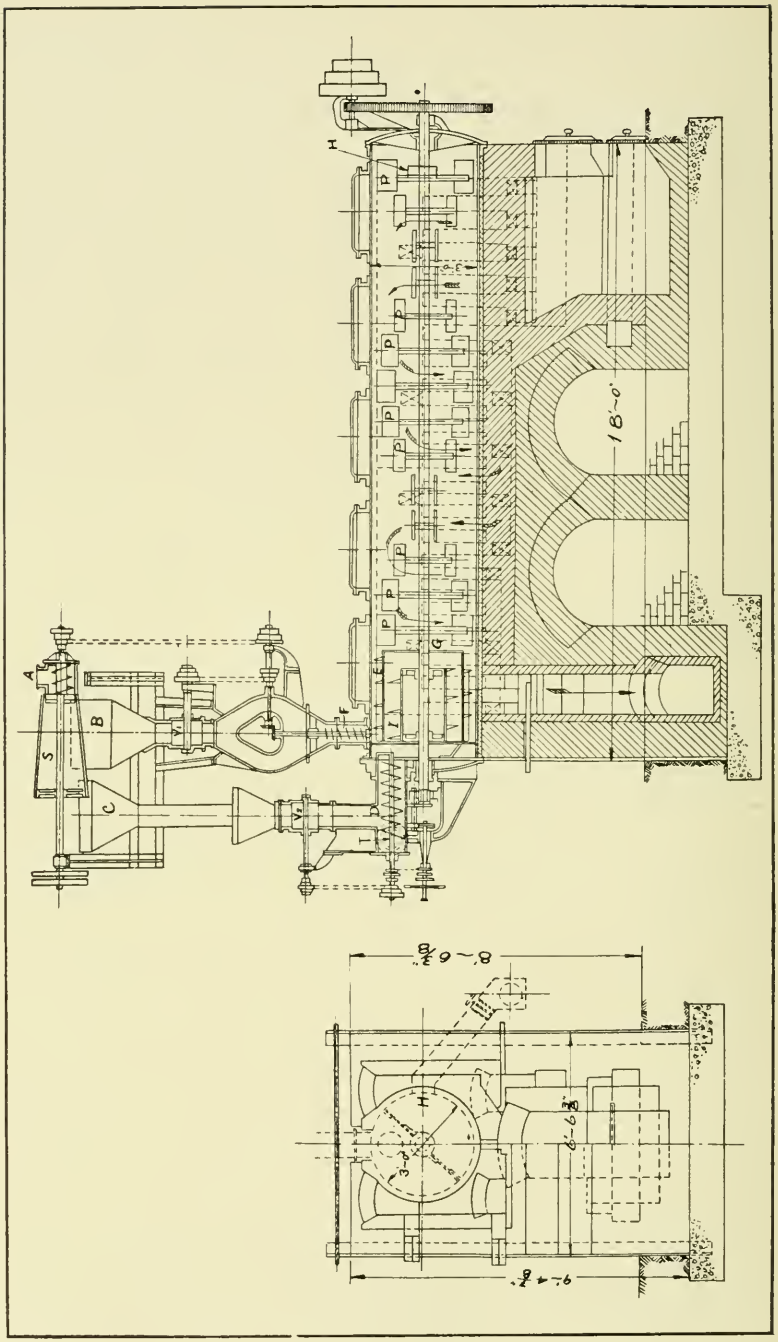

Fig. 4. The "Asorbus" Carboniser.

design, and serve to feed a definite amount of coal regularly and automatically, at the same time keeping the carboniser absolutely air tight. The coarser coal is fed separately for the purpose of using it as a tar filter, as is explained later. The green coal thus charged is carried forward by means of screwed drums E and I, and is mixed together at G. Thereafter, the coal travels towards the other end of the retort, being continuously agitated by the rotation of paddled agitators P, which revolve with the drums I and E at the rate of seven to eight revolutions per minute.

The carboniser is externally fired, and the agitation keeps the coal uniformly heated and accelerates carbonisation. After about thirty minutes the coal emerges from the hole H as semi-coke in a fine state, while the tar oil distilled out moves in the opposite direction through the layer of heated coal in the carboniser, and coarser green coal at I and D, and is finally discharged into the tar cooler through the pipe T, at the extreme left end of the dust arrester. In this way the tar oil is thoroughly filtered by the coal layer through which it passes, and is entirely freed from dust and any other solid material, so that the tar-carrying pipe is always clean, and no clogging occurs even after continuous working of the carboniser for several weeks.

On the mine sites everywhere in the north-eastern district, the weathered fines are abandoned in heaps and some of them are found burning spontaneously, yet the analyses of these abandoned fines proves that they contain a considerable amount of combustibles, as shown in Table VI.

TABLE VI

ANALYSES OF WEATHERED BROWN COALS

	Name of Coal.	Moisture per cent.	Tar per cent.	Gas per cent.	Fixed carbon per cent.	Ash per cent.
"Asorbus" Analyses	Hogi	26·275	8·733	15·740	31·925	17·324
	Keirin ...	24·918	10·125	15·077	37·817	12·060
	Kwainei ...	22·12	9·13	13·02	33·04	22·69
	Seikirei ...	18·90	13·10	16·60	28·29	23·01

	Name of Coal.	Moisture per cent.	Volatile matter per cent.	Fixed carbon per cent.	Ash per cent.	Sulphur per cent.	Calorific value.
Technical Analyses	Hogi ...	18·603	32·557	31·529	17·310	0·807	4903·33
	Keirin ...	18·262	33·575	36·102	12·060	0·960	5654·48
	Kwainei ...	17·20	27·69	32·42	23·69	0·49	5077·50
	Seikirei ...	12·90	36·48	27·61	23·01	1·58	4542·56

Experimental Results

The first step taken, therefore, was to examine whether these apparently useless fines could not be converted into useful fuel by the process of carbonising. After some preliminary trials, 500°C. was found to be the most suitable temperature for the treatment of this sort of coal, and four varieties of weathered fines were carbonised at this temperature in the "Asorbus" retort, the total amount treated being about 25 tons of each. The results are as shown in Tables VII, VIII (A), and VIII (B).

TABLE VII

CARBONISATION PRODUCTS OF WEATHERED BROWN COAL

	Name of Coal.			
	Hogi.	Keirin.	Kwainei.	Seikirei.
Duration of test when records were taken	45 hrs.	58 hrs. 45 min.	56 hrs. 30 min.	48 hrs.
Tons of carbonised coal (total) ...	9·03	12·4	10·92	8·16
Tons of coal per day of 24 hours...	5·04	4·976	4·639	4·08
Average carbonising temperature °C.	500	500	500	500
Total weight of tar actually obtained in kilos.	796·776	1201·997	937·074	997·889
Percentage of tar obtained on wet basis	8·567	9·701	8·581	12·229
Percentage of tar obtained on dry basis	10·526	11·869	10·364	14·040
Percentage of tar/total tar content in the distilled coal	98·13	95·84	93·99	93·35
Total weight of semi-coke actually obtained in kilos	5131·7	6823·6	6560·6	4831·5
Percentage of semi-coke actually obtained ... on wet basis	56·83	55·10	60·1	59·2
Percentage of semi-coke actually obtained ... on dry basis	69·5	66·5	72·1	67·5
Calorific value ... ... Calories	6576·4	7156·5	6028·0	5081·0
Percentage increase of calorific value against original coal ... ... on wet basis	34·1	26·6	18·7	11·9
Percentage increase of calorific value against original coal ... ... on dry basis	9·78	4·86	1·1	1·4
Volume of gas actually generated M^3	786·20	1205·20	648·30	964·91
M^3 of gas generated per ton of coal on wet basis	87·07	97·27	69·99	118·25
M^3 of gas generated per ton of coal on dry basis	106·96	119·00	84·53	135·76
Calorific value of generated gas Calories/M^3	5684·6	6528·2	6406·3	6382·0

TABLE VIII (A)

ANALYSES OF THE PRODUCTS OF CARBONISATION (TAR)

		Name of Coal.			
		Hogi.	Keirin.	Kwainei.	Seikirei.
Specific gravity at 15°C. ...		0·9532	0·9535	0·9488	0·9501 at 22°
Flash point ... °C. ...		28·76	21·48	20·55	36·80
Burning point °C. ...		59·83	25·17	23·17	64·80
Solidifying temp. °C. ...		2·25	2·45	3·60	0·65
Calorific value Calories		9242·0	9808·1	9859·0	8969·4
Free carbon ... per cent.		0·792	0·271	0·695	1·330
Paraffin ... ,,		2·242	2·194	3·280	1·940
Sulphur ... ,,		0·610	0·658	0·559	0·453
Ash ... ... ,,		0·048	0·062	0·039	0·174
Viscosity by "Engler"	at 15°C.... ...	2·0225	1·8321	1·7076	—
	at 20°C.... ...	1·6968	1·6083	1·5343	1·5121
	at 30°C.... ...	1·4747	1·3863	1·3448	1·5018
	at 40°C.... ...	1·3718	1·2762	1·2708	1·3031
	at 50°C.... ...	1·2960	1·2112	1·1823	1·2789

TABLE VIII (B)

ANALYSES OF THE PRODUCTS OF CARBONISATION (SEMI-COKE AND GAS)

			Name of Coal.			
			Hogi.	Keirin.	Kwainei	Seikirei.
Semi-coke	"Asorbus" Analysis	Moisture	per cent. 1·02	per cent. 0·992	per cent. 0·831	per cent. 1·290
		Tar	0·44	0·528	0·418	0·320
		Gas	10·93	9·500	6·825	8·760
		Fixed carbon ...	61·91	67·240	58·373	58·170
		Ash	25·70	21·810	33·553	31·460
	Technical Analysis	Moisture	0·058	1·338	0·633	1·22
		Volatile matter ...	13·397	10·843	12·617	10·63
		Fixed carbon ...	60·416	66·875	53·790	56·86
		Ash	25·626	20·943	32·960	31·29
		Sulphur	1·211	1·175	0·560	1·75
Gas		Carbon dioxide ...	26·200	20·124	16·687	21·187
		Oxygen	1·108	1·503	1·350	1·738
		Carbon monoxide ...	4·091	7·550	6·131	4·294
		Hydrogen	12·946	12·683	13·973	9·747
		Methane series	31·197	46·288	50·248	48·140
		Higher hydrocarbons ...	6·237	6·103	5·915	7·485
		Nitrogen	18·997	5·746	5·692	7·409

As will be seen from these tables, the tar oil distilled out is about 95 to 98 per cent. of the the original content, and the semi-coke obtained is 55 to 60 per cent. of the carbonised fines. The calorific

value of the semi-coke is 12 to 34 per cent. in excess of that of the original fines, and the pulverised firing of this fuel proved that it is the most reliable fuel burnt in a boiler, giving much less ash trouble than in the case of anthracite.

The lightest oil obtained by fractional distillation up to 150°C. amounts to 8 to 10 per cent. of the tar oil, and after saturation of the unsaturated hydrocarbons contained, the resulting permanently clear oil amounts to 80 per cent. of the original distillate, and can be satisfactorily used for gasoline engines, while the kerosene distilled out between 150° and 250°C., as in the case of natural petroleum, is suitable for driving kerosene engines.

Utilisation of Brown Coal Fines

In this way, the abandoned weathered fines proved to be valuable fuel, when carbonised at low temperature. If this treatment is carried out on the site, a small expenditure only is necessary for the original staff, and the capital outlay for the carbonising plant will be easily paid back within four or five years, even with the sale of tar oil only. The publication of the results of the above-mentioned experiment aroused among mineowners a strong desire to establish the plant for the treatment of this wasted fines, and it is expected that this scheme will be put into effect when the present financial situation in Japan is re-adjusted.

With raw brown coal, the analysis shows that the tar content is far in excess of that of the weathered fines, being generally higher than 12 per cent., as is mentioned elsewhere in this paper. Moreover, some preliminary experiments show that ammonium sulphate could be collected from the tar oil washing at the rate of about five pounds per ton of coal, and the economic aspect of establishing a power station with carbonising plant and semi-coke fired boilers is very promising.

It is expected that our experiments with several varieties of raw brown coals will be finished by the end of 1928, when we hope to publish the results obtained and discuss the future prospect in greater detail.

CONCLUSION

It may be a little premature to draw any conclusion from what has been mentioned in this paper, as further experimental work still remains to be conducted. But the results so far arrived at

indicate that the pulverised firing of anthracite, and low-temperature distillation of brown coal combined with pulverised fuel firing, when carried out at the mine, are very efficient ways of utilising Korean coal, both from the technical and the economic points of view.

It is, therefore, our ambition to establish suitable power plants on the site of all coal mines developed, in order to convert the fuel into electrical energy at the spot where it is mined, and to interconnect them with transmission trunk lines, which, in turn, will distribute electrically the latent energy of coal into all the principal cities and industrial districts in the Korean peninsula.

Fortunately, practically all the important coal measures in the north-eastern district cross the River Tumen (one of the five biggest rivers in Korea), on the Russian border. Consequently, the principal brown coal mines can obtain an abundance of water supply quite easily. In the "Heijo" anthracite district there is the River Tantong flowing through the middle of the field; and at almost all other mines now developed we have main or tributary streams flowing close by. These geographical conditions facilitate the efficient working of steam plant at the pit-head.

By the adoption of the foregoing system the entire power resources can be developed most efficiently with the minimum loss through transportation; and the consequent lowering of price, and abundant supply of power will largely contribute towards the promotion of industry in Korea; in addition, there results the increased home production of oil.

In Korea, the electrical industry is still in its infancy, and the unification of installations can be accomplished much more easily than anywhere else. This fact doubly enhances the efficiency of the trunk-line system, and we expect that the results of further experiments in the Institute will confirm the advisability of carrying out the above-mentioned scheme.

RÉSUMÉ

En Corée, le charbon produit est soit de l'anthracite, soit du lignite. Malgré les réserves naturelles assez importantes, les méthodes d'exploitation ne sont pas encore suffisamment développées, de sorte que le 80 pour cent de la consommation totale de charbon doit être importé. Par conséquent les combustibles, et de ce fait l'énergie industrielle, sont très chers. Ces circonstances sont susceptibles de retarder considérablement le développement de l'industrie en Corée.

L'Institut scientifique des combustibles du Governement de Corée a été

créé dans le but de faire des recherches pour l'utilisation rationnelle des charbons du pays. Les expériences faites à l'Institut ont prouvé que même l'anthracite ne contenant que 3 pour cent de matière volatile peut être brûlé dans les chaudières d'une façon satisfaisante sous forme pulvérisée, tandisque le lignite soumis à la distillation à basse température donne 10 à 12 pour cent d'huile de gourdon et le combustible résultant peut être utilisé efficacement sous forme pulvérisée.

Le lignite est surtout produit dans des régions où les moyens de transport sont très limités; en outre il a l'inconvénient de s'altérer très rapidement sous l'influence des éléments.

Il s'en suit que la meilleure façon de tirer parti des charbons de Corée est de les transformer sur place en énergie électrique et de diriger celle-ci par des lignes de transmission vers les villes principales et les centres industriels de la péninsule coréenne.

Dans le cas du lignite, le système générateur doit être muni d'une cornue de carbonisation à basse température; le lignite est ainsi soumis au processus d'extraction du goudron avant d'être transformé en énergie électrique.

Le rapport donne une courte récapitulation des diverses expériences faites à l'Institut qui nous ont menés aux conclusions que nous venons de décrire.

QUELQUES CONSIDÉRATIONS GÉNÉRALES SUR L'UTILISATION RATIONNELLE DES LIGNITES DE ROUMANIE

(SOME CONSIDERATIONS REGARDING THE RATIONAL UTILISATION OF ROUMANIAN LIGNITES)

ROUMANIAN NATIONAL COMMITTEE, WORLD POWER CONFERENCE

I. BUJOIU

*Paper No. A*10

CONTENTS

LIGNITE RESERVES—THE PROBLEM OF RATIONAL UTILISATION—EXPERIMENTAL WORK—RECOMMENDATIONS—RÉSUMÉ

Le problème des lignites, du point de vue de la réserve d'énergie qu'ils contiennent, apparaît en Roumanie sous un aspect différent que dans d'autres pays.

En effet, la Roumanie produit des pétroles et le mazout fait une concurrence acharnée aux lignites, autant par son pouvoir calorifique élevé que par sa manutention facile. En ce qui concerne les sous-produits de la distillation, il est évident que le benzol et les huiles extraites des lignites peuvent difficilement être placés sur un marché qui produit l'essence et les huiles de pétrole à bon marché.

Un autre élément qui complique encore le problème de l'utilisation des lignites est le bois de chauffage, plus abondant que dans d'autres pays. Les énormes quantités de bois de hêtre et les déchets des exploitations de bois de construction, tous les deux avec un prix de revient réduit, interdisent presque l'utilisation d'un autre combustible pour les besoins domestiques et même pour de grandes fabriques.

Dans de semblables conditions, la mise en valeur des lignites demandera pour la Roumanie des études profondes et détaillées, pour une utilisation aussi rationnelle que possible de toutes leurs qualités.

Le gouvernement roumain, dans l'intention d'utiliser aussi rationnellement que possible, et en même temps en concordance, les sources variées d'énergie du pays, comme pétrole, charbons, lignites, gaz naturel, chûtes d'eau etc., a nommé dès le 29 Juillet 1922 une "commission pour l'électrification du pays et pour la coordination de l'exploitation de ses facteurs naturels producteurs d'énergie" qui a commencé ses travaux sous la présidence de M. le professeur Mrazec, directeur de l'institut géologique de Roumanie.

La commission a commencé par faire étudier par les organes de l'institut géologique, comme il était du reste naturel, les réserves de combustible solide et une série d'études ont été publiées sur les principaux bassins de charbon et de lignites.[1] La carte[2] que nous annexons montre en résumé, en millions de tonnes et millions de kW., la répartition des réserves connues fin 1925.

En examinant sur la carte les divers centres producteurs de lignites, disséminés sur tout le territoire du pays, nous constatons que le total des réserves enregistrées monte à 2241,5 mil. tonnes on 1.092.102,4 mil. kW., chiffre assez important surtout si l'on considère que les évaluations ont été faites avec une grande prudence. Les chiffres cités peuvent plutôt être considérés comme réserve probable à l'exclusion de celle possible.

Si nous suivons dans la région des collines qui contournent l'arc carpatique, du Danube jusqu'en Bucovine, les formations géologiques, les affleurements, les sondages des régions pétrolifères etc., nous pouvons affirmer, avec assez de précision, la continuité des gisements de lignite sur toute leur étendue avec certaines interruptions. En joignant à ces formations avec charbon du pliocène inférieur et surtout supérieur, les bassins importants de la Transylvanie du pliocène, oligocène, méditerranéen supérieur et inférieur, les chiffres cités plus haut peuvent être considérablement augmentés. En tout cas, les réserves de charbons bruns et lignites sont de telle nature, que l'on peut compter sur une production de longue durée

[1] Carbunii liasici din împrejurimile Braşovului par E. Jekelius.
Zacamintele de lignit din basinul pliocenic din Valea superioara a Oltului par E. Jekelius.
Zacamintele de lignit din basinul pliocenic dela Borsec par D. Atanasiu.
Zacamintele de lignit din pliocenul Olteniei par Grozescu.
Zacamintele de lignit din pliocenul de lânga Curtea de Arges si împrejurimile Campulungului par O. Protescu.
Sous presse: Lignitele din Jud. Prahova, Buzau, Dâmbovita par O. Protescu.

[2] Schita zacamintelor de carbuni din România cu rezervele lor în mil. KWO par Ing. M. Sophian d'après M.M. le prof. Dr. Sava Atanasiu, Prof. Dr. Gh. Macivei, Dr. H. Grozescu, Dr. O. Bardescu, I. Atanasiu, Dr. E. Jekelius et Dr. Papp Karoly.

sur laquelle se peuvent baser tous calculs d'industrialisation et d'amortisation.

Le problème de l'utilisation rationnelle des lignites peut se poser de 3 façons différentes:

(1) Trouver un dispositif pour la combustion parfaitement adapté aux caractéristiques des lignites.

(2) Adaptation des lignites, par des modifications physiques, pour leur utilisation aussi rationnelle que possible dans des installations à grand rendement.

(3) Modification de la constitution et ennoblissement des lignites pour être utilisés comme produits supérieurs pour les emplois réservés jusqu'ici aux combustibles supérieurs.

On voit, de ce qui précède, que l'utilisation des lignites est uniquement comprise sous forme de combustible. Son utilisation, comme produit brut, sous d'autres formes (gazogènes, produits chimiques, etc.), est très réduite et ne mérite pas une mention spéciale.

La résolution du premier point entre dans le domaine de la construction des grilles, des voûtes et des chaudières, résolution qui n'entre pas dans le cadre de cette communication. Il sera suffisant de dire que les résultats dans ce domaine paraissent être assez bons et que les grilles en cascade (Treppenrost) et les grilles mécaniques (rotatives) avec des surfaces correspondantes donnent satisfaction pour les lignites de Roumanie.

De même, l'adaptation des lignites pour une utilisation rationnelle, notamment leur assèchement par divers procédés, ne présente aucune difficulté caractéristique pour les lignites roumains et le briquettage des produits séchés, autant pour les usages domestiques que pour l'emploi industriel, peut se faire facilement par les procédés connus. D'autre part, la pulvérisation des lignites et la combustion dans les foyers par insufflation a donné de très bons résultats et je cite à ce sujet les essais faits avec les charbons de Lupeni avec le système Lopulco à la station d'essais de la Société Kohlenscheidung, Berlin.

Le charbon soumis aux essais était menu (0-10 mm.) avec 3,5 pour cent d'humidité et a été moulu à la dimension de 900 mailles par cm^2, avec 0,4 pour cent de refus ou à 4900 mailles par cm^2 avec 12,5 pour cent de refus ne passant pas au tamis. Le moulin a consommé par tonne moulue 14,1 kW. Si l'on s'arrêtait au produit à 4900 mailles par cm^2 avec 15,5 pour cent de refus, produit encore très bon, l'énergie consommée ne serait que de 12,5 kW./t. Les résultats de la combustion ont été aussi satisfaisants que possible.

Dans une chaudière timbrée à 37 kg./cm² et de 660 m² la combustion a été complète, le pourcentage de CO_2 a été de 13 et le rendement de l'installation de 86,8 pour cent. On peut voir d'après ces résultats que les lignites roumains peuvent être adaptés aux installations modernes de combustion sous forme de charbon pulvérisé sans aucune difficulté.

Les méthodes énumérées plus haut, pour la rationalisation de l'emploi des lignites, améliorent de beaucoup la combustion mais ne peuvent toutefois lutter contre la concurrence des autres combustibles, et cela pour les raisons citées plus haut. C'est pour cela que les méthodes qui extraient les parties nobles des lignites en produisant en même temps un combustible supérieur sont plus indiquées et la distillation à basses températures a formé l'objet de recherches sérieuses. Dans les laboratoires de l'Ecole Polytechnique de Timisoara, on a poursuivi des études[3] sur 39 échantillons de lignites divers de Roumanie, dont les résultats sont consignés dans le tableau No. 1. On voit que si les lignites traités n'ont pas trop de cendres le pouvoir calorifique du semi-coke obtenu est grand. En ce qui concerne la quantité obtenue, elle dépend en premier lieu du contenu en eau du produit premier. Le pourcentage de goudron varie entre 3,10 et 15,21.

Des études plus approfondies ont été faites sous la direction de MM. le prof. N. Danaila et l'ing. J. Blum à l'institut de chimie industrielle de la faculté des sciences de Bucarest.[4] Les essais ont été faits sur quatre échantillons de lignites. Trois d'entre eux étant considérés comme représentant les catégories moyennes des lignites roumains, les lignites proprement dits, les charbons bruns et les charbons de la Vallée du Jiu, c'est-à-dire des lignites supérieurs faisant la transition vers la houille.[5] Tous les lignites de la Valachie, Moldavie, Transylvanie et du Banat peuvent être rapprochés à l'une de ces catégories. Les échantillons ont été pris dans les mines de Jidava-Pescareasa, Comanesti et Lupeni. (A observer le pourcentage de cendres de l'échantillon de Lupeni, pourcentage anormal d'après le tableau No. 1 et qui modifie la valeur réelle de ce produit). Le quatrième échantillon a été pris dans les mines de Pralea et

[3] Lignitele din România par Mr. J. Christesco et Ad. Sandor.

[4] Sur l'utilisation rationnelle des lignites roumains : la distillation à de basses températures. Communication faite à la Société Roumaine des sciences par MM. le prof. N. Danaila et l'ing. J. Blum.

[5] D'après la classification de Toronto on aurait:
Jidava classe D2, Comanesti classe D1, Pralea classe D2, Lupeni classe C.

TABLEAU No. 4

ANALYSE DU COKE PRIMAIRE, OBTENU PAR DISTILLATION, À DE BASSES TEMPÉRATURES, DANS LE FOUR ROTATIF DES QUATRE ÉCHANTILLONS DE LIGNITE

Spécification de l'echantillon dont provient le coke.	Composition générale.		Analyse élémentaire.					Cokéfaction.	Analyse sommaire.		Pouvoir calorifique.
	Cendre %	Matières combustibles. %	C %	H %	S %	N %	O %	Coke. %	Charbon fixe. %	Matières volatiles. %	Calories par kg.
Jidava-Pescareasca ...	19,86	80,14	62,82	2,58	0,36	1,33	13,05	88,56	68,70	11,44	5994,3
Comanesti-Vermesti ...	17,63	82,34	64,17	2,63	1,95	1,42	12,17	89,08	71,42	10,92	5628,3
Lupeni	38,79	61,21	48,56	2,05	1,84	1,46	7,30	92,86	54,07	7,14	4665,7
Pralea	27,05	72,95	48,69	2,85	0,32	0,84	20,25	87,16	60,11	12,84	4322,0

représente le type le plus inférieur des lignites de Roumanie. Les résultats analytiques de ces lignites sont consignés dans le tableau No. 2. Les essais ont été faits dans des cornues fixes avec et sans injection de vapeur, système F. Fischer et H. Schrader et dans un four rotatif horizontal avec chauffage extérieur faisant 2-3 tours par minute et avec un dispositif permettant l'injection de vapeur pour la distillation et pour le nettoyage en fin d'opération des restes de gaz et goudrons. Le chauffage se faisait au gaz. La durée d'une distillation a été de 4-5 heures et la pression n'a jamais dépassé 500 mm. d'eau. L'élévation de la température a été conduite de telle façon que les produits de distillation passaient régulièrement et avec continuité en évitant les altérations. Par exemple la distillation des échantillons des mines de Jidava-Pescareasa a été faite en chauffant pendant la première demi-heure jusqu'à 100°C., on distillait ainsi l'eau de composition, et on évacuait une partie de l'air dilaté et une certaine quantité de gaz incombustible. A 300°C. les gaz combustibles commencent à apparaître et vers 320° apparaissent aussi les goudrons. A partir de ce point on élève la température de 100° par heure sans que la pression ne varie. On maintient le four pendant une demi-heure à 500°, température à laquelle ne distillent plus que de rares gouttes de goudron; on passe ensuite un courant de vapeur et on arrête l'opération en pesant le semi-coke obtenu. Les résultats moyens d'une longue série de distillations pour chaque catégorie a conduit aux résultats consignés dans le tableau No. 3.

Le coke produit à partir des lignites proprement dits et des charbons bruns conserve en général la structure du lignite distillé. Dès qu'il est sorti de la cornue ou du four il a un aspect luisant, mais peu de jours après il devient noir mat, semblable au charbon de bois. Le coke de Lupeni, étant donnée la tendance à l'agglomération de ces charbons, a l'aspect des cokes obtenus par la distillation à haute température.

Les résultats analytiques des différents types de coke sont consignés dans le tableau No. 4. A remarquer que le coke de Lupeni, provenant d'un charbon avec beaucoup de cendres, a un pouvoir calorifique faible. Les résultats seraient bien meilleurs avec un charbon de Lupeni normal. Le coke obtenu brûle facilement sans fumée.

Les caractères des goudrons obtenus à la distillation sont marquées dans le tableau No. 5.

TABLEAU No. 5.

CONSTANTES PHYSIQUES ET POUVOIRS CALORIFIQUES DES GOUDRONS

Spécification de l'échantillon dont les goudrons ont été obtenus.	Température à laquelle apparaît le goudron.	D.15°C.	Point de congélation.		Pouvoir calorifique par kg.	Aspect extérieur
			Méthode galicienne.	Dans l'éprouvette.		
					cal.	
Jidava-Pescaresca	320°C.	0,971	+34°C.	+25°C.	6.866	Noir-café Solide à température ordinaire Odeur de H_2S.
Comanesti-Vermesti ...	340°–350°C.	1,001	+34°C.	+24°C.	7.090	Noir Solide à température ordinaire Odeur de H_2S.
Lupeni	315°C.	1,000	+28°C.	+19°C.	8.653	Noir Mi-solide à temtempérature ordinaire Odeur de H_2S.
Pralea	340°C.	1,020	+36°C.	+26°C.	6.308	Noir-café Solide à température ordinaire Odeur de H_2S.

En distillant les goudrons à l'aide de vapeur surchauffée dans l'appareil recommandé par F. Fischer, on obtient quatre groupes de produits:

(*a*) Une première fraction qui distille jusqu'à 180°, au début incolore, qui se colore ensuite en jaune et passe au verdâtre à la fin. En présence de l'air ce produit se colore en rouge. De 100 gr. de goudrons on obtient 24,4 à 35 gr., qui, rapportés à 100 gr. de charbon, reviennent à 0,91-2,38 pour cent. La densité du produit varie de 0,9142 à 0,9471 et après extraction des phénols baisse à 0,818-0,855.

(*b*) La 2e fraction distille entre 180° et 240°C. et donne par condensation un liquide vert, contenant de la paraffine et présentant une tendance de congélation dans le tube de réfrigération. Pour 100 gr. de goudrons ont passé 23,9 à 29,5 gr. ce qui rapporté à 100 gr. de charbon, revient à 1,30-2,21 pour cent. La densité à 15°C. varie de 0,969 à 0,999.

(*c*) La 3e fraction distille entre 240° et 270° et on obtient un liquide de couleur jaune-rouge, qui se solidifie dans le tube de réfrigération. Le pourcentage de cette fraction varie de 11,6 à 26,4

et rapporté au charbon de 0,43 à 2,44 gr. pour 100 gr. de charbon. La densité à 15° varie de 0,925 à 1,000.

(*d*) La dernière fraction est le brai, qui reste comme résidu et représente pour 100 gr. de goudron 17 à 26,4 gr. ou, rapporté à 100 gr. de charbon, de 0,82 à 1.85 gr.

L'eau distillée varie de 2,5 pour cent à 5,5 pour cent.

Le gaz obtenu à la distillation varie entre 50 et 130 m^3 par tonne de lignite, le pouvoir calorifique est de 3785 cal. pour le lignite de Jidava, 6018 pour Comanesti, 9052 pour Lupeni et 3183 pour Pralea. Si ce gaz est épuré du CO_2 et H_2S les pouvoirs calorifiques respectifs passent à 8618, 10328, 10140 et 5201.

Le benzol extrait des gaz, à l'aide du charbon actif, est un liquide jaune et la couleur devient plus foncée par l'exposition à l'air. Les résultats des distillations faites de la même façon sur une tonne de lignite séché (à 105°C.) sont consignés dans les tableaux No. 6 et No. 7.

TABLEAU No. 6

PRODUITS DISTILLÉS DU FOUR ROTATIF, RAPPORTÉS À UNE TONNE DE CHARBON SEC (à 105°C.).

Spécification de l'échantillon.	Coke en kg.	Goudron en kg.	Benzine des gaz en kg.	Gaz en m^3.	Eau en kg.
	env.	env.	env.	env.	env.
Jidava-Pescareasca ...	640	81	1,45	120	90
Comanesti-Vermesti ...	680	68	1,45	100	110
Lupeni	770	89	1,47	50	60
Pralea	610	69	1,36	130	100

TABLEAU No. 7

TRAITEMENT DU GOUDRON, RÉSULTATS RAPPORTÉS À UNE TONNE DE LIGNITE SEC (à 105°C.)

Spécification de échantillon.	Benzine brute en kg.	Huiles brutes en kg.	Huiles phéno-liques en litres.	Paraf-fine en kg.	Brai en kg.
	env.	env.	env.	env.	env.
Jidava Pescareasca ...	2,45	35	25	2,16	13,87
Comanesti-Vermesti ...	1,78	30	20	1,9	14,5
Lupeni	1,96	43	21	2,47	20,0
Pralea	2,01	29	20	2,6	15,47

Les conclusions des études de MM. N. Danaila et J. Blum sur les lignites roumains peuvent se résumer de la façon suivante:

(1) Les lignites roumains distillent jusqu'à 500° donnant un coke friable qui brûle bien sans fumée. Le rendement énergétique du

coke représente 65-80 pour cent du pouvoir calorifique des lignites desquels il provient.

(2) La quantité de goudrons, rapportée au lignite sec à 105°, est de 6,8-9 pour cent et les calories contenues représentent 8-15 pour cent du pouvoir calorifique total du lignite initial.

(3) Les gaz obtenus par distillation jusqu'à 500° rapportés à une tonne de charbon sec, varient de 50 à 130 m^3, avec un pouvoir calorifique de 3335 à 9094 cal/m^3; leur rendement énergétique représente 7-16 pour cent du pouvoir calorifique total des lignites desquels ils proviennent.

(4) Le bilan thermique de chaque espèce de lignite montre que l'énergie consommée pour la distillation est d'autant plus petite que le lignite est de meilleure qualité (161.022 cal. pour une tonne de Lupeni, 382.388 cal. pour une tonne de Pralea).

De ce qui précède, nous voyons que la distillation à basse température des lignites roumains permet de les utiliser rationnellement du moment que l'on obtient des combustibles supérieurs, tels que le coke et les gaz, et d'autre part des goudrons, du benzol, de la paraffine, etc., produits nobles qui peuvent avoir une autre utilisation, plus avantageuse que la combustion dans des foyers de chaudières.

Nous avons vu que le coke de lignite a suffisamment de matières volatiles pour brûler sur les grilles, qu'il peut être pulvérisé et insufflé dans les foyers et est très apte pour l'emploi dans les gazogènes. Mais là où il devrait avoir une certaine résistance ou une forme spéciale pour la manutention, le coke primaire, tel qu'il sort de la distillation, n'est pas convenable, étant trop friable, et le briquettage s'impose.

L'institut de chimie industrielle, continuant les études sur l'utilisation rationnelle des combustibles, s'est occupé du briquettage[6] du coke de lignite obtenu par les distillations citées.

En premier lieu on a recherché l'obtention d'un liant provenant soit de produits de pétrole, soit des goudrons de distillation, soit d'un mélange des deux. On a trouvé que les conditions que ce liant doit remplir sont:

Brai de pétrole: obtenu des résidus du pétrole; le point de fusion doit être d'au moins 61-63°C.; il ne doit pas distiller avant 300°C.

[6] Sur l'utilisation rationnelle des lignites roumains.
Essais sur le briquettage du coke primaire.
Communication faite à la société roumaine des sciences par M. l'ingénieur J. Blum.

Brai de charbon: extrait du goudron primaire par distillation et oxydation partielle, en obtenant environ 45 pour cent de la quantité de goudron traité. Le point de fusion doit être d'au moins 41 à 43° et le brai ne doit pas distiller avec des vapeurs surchauffées avant 190°C.

En faisant divers essais sur les briquettes obtenues on a constaté que les dimensions et les proportions optima pour employer le minimum de liant tout en obtenant des briquettes de résistance maxima sont:

Coke de	0 à 0,5 mm.	20	pour cent
,,	1 ,, 5 mm.	60	,,
,,	5 ,, 8 mm.	20	,,

Le pourcentage de brai utilisé varie de 6½ pour cent à 7 pour cent et se compose de 97 pour cent brai de distillation de lignite et seulement de 3 pour cent de brai de pétrole. La pression de fabrication des briquettes est de 300 kg./cm². Les briquettes obtenues étaient noires, luisantes, brûlaient bien et se maintenaient dans le feu jusqu'à consommation complète. A tous les points de vue elles se sont comportées comme des combustibles supérieurs.

En résumant ce qui vient d'être exposé, il résulte qu'il est d'une nécessité absolue pour l'industrie des lignites de la Roumanie d'en rationaliser l'emploi à cause de la concurrence qu'elle doit supporter de la part des pétroles et du bois de chauffage. Les lignites roumains sont aptes pour les différentes adaptations en vue de l'obtention d'un bon rendement de la combustion et pour leur transformation par distillation à basse température en produits plus nobles ou de rendement supérieur, d'où une rémunération plus grande pour les industries utilisant les lignites sous ces formes.

Le problème de l'utilisation rationnelle des lignites en Roumanie doit être envisagé sous un aspect plus général, celui de la coordination des sources d'énergie par le lignite et des autres sources d'énergie afin d'obtenir une alimentation rationnelle du pays en énergie. Parallèlement au développement industriel du pays, la demande d'énergie a augmenté et pour la satisfaire il faut une étude approfondie. En effet, la Roumanie possède du pétrole, des gaz, du charbon et des lignites, de l'énergie hydraulique et des bois. Lesquelles de ces sources doivent être utilisées et de quelle façon?

La solution qui sera adoptée ne devra pas être choisie uniquement d'après des considérations purement techniques, car des éléments d'ordre général économiques et financiers peuvent intervenir comme facteurs importants. Ainsi quoique le pétrole, par son prix de

revient et par son pouvoir calorifique soit un détenteur d'énergie de premier ordre, sa valeur mondiale et la facilité de manutention le recommandent comme un article principal d'exportation. La Roumanie, qui par l'extension industrielle survenue après la guerre est forcée à une forte importation, pour se créer l'outillage nécessaire, doit exporter le plus de produits de pétrole possible pour équilibrer sa balance commerciale.

Bien entendu que là où les produits du pétrole ne peuvent être remplacés par une autre source d'énergie ou bien là où l'unité d'énergie produite par d'autres sources reviendrait trop cher, l'utilisation du pétrole reste indiquée.

Le gaz, par son pouvoir calorifique, est une source d'énergie intéressante et le seul désavantage qu'il présente est qu'il ne peut être considéré comme une solution de longue durée, les quantités disponibles étant limitées. Toutefois le prix de revient réduit et l'obligation de le consommer à faible distance du lieu de production l'indique comme source d'énergie devant être mise en valeur par des centrales thermoélectriques.

Un problème difficile à résoudre et qui se discute partout est la rivalité entre les centrales thermiques et les centrales hydrauliques.

En ce qui concerne la Roumanie la solution technique est fortement influencée par les conditions économiques et naturelles. En effet, le prix de premier établissement des centrales hydrauliques par rapport aux centrales thermiques est beaucoup plus élevé et aujourd'hui, quand la Roumanie a besoin d'investissements dans toutes les branches, les sommes dépensées en plus pour la solution hydraulique représenteraient une charge très lourde. D'autre part, l'industrie roumaine, encore neuve, a besoin d'énergie à bon marché pour se consolider et ne peut supporter l'amortissement qui grève d'autant plus le kW. hydraulique que ces centrales sont conditionnées bien plus par des facteurs naturels que par les consommateurs, d'où il résulte qu'on installera dès le début des unités trop grandes. Les centrales thermiques présentent parcontre, une formule plus souple, elles pourront suivre facilement les demandes d'énergie et par cela le prix du kW. sera réduit.

L'installation de grandes centrales hydrauliques est encore rendue difficile en Roumanie par le fait que le régime des eaux n'est pas trop favorable et que les dépenses d'aménagement pour les chûtes d'eau seraient très grandes et hors de proportion avec les dépenses similaires en Suisse, Italie, Suède, Norvège, etc.

Ce qui précède n'exclue pas l'adoption de la solution hydraulique là où les conditions locales sont avantageuses.

La solution la plus juste pour la Roumanie ne peut être l'adoption exclusive soit de l'énergie hydraulique, soit thermique. Une collaboration de ces deux sources, utilisant l'énergie hydraulique en tant que cela ne demanderait pas de trop grands travaux et là seulement où la distribution du courant est déjà préparée par des centrales thermiques, est la solution la plus judicieuse. Ainsi la solution hydraulique a été adoptée pour une centrale à Scropoasa sur la Ialomita qui, parallèlement avec une centrale thermique dont l'emplacement est indiqué dans la région de Doicesti, fournira le surplus de courant nécessaire à la capitale du pays et aux régions pétrolifères. Des études extrêmement intéressantes ont été faites pour l'utilisation de l'énergie de la Bistriţa dans une centrale électrique qui, parallèlement à une centrale thermique située dans la région de Comanesti, couvrira les besoins d'énergie de la basse Moldavie et de la partie Sud-Est de la Transylvanie. L'électrification du pays devra être complétée par deux centrales hydrauliques, l'une sur le Jiu, l'autre sur le Râul Barbat ou le Râul Mare, centrales qui, en parallèle avec une supercentrale thermique dans la Vallée du Jiu, alimenteront, l'une l'Olténie, l'autre la région industrielle du sud-ouest du pays. Enfin une région qui se développera et qui aura besoin de courant hydroélectrique pour l'industrie de l'aluminium, qui se créera, est la région située entre les villes de Cluj et Oradea Mare, ces deux villes y comprises. Bien entendu que cette centrale aussi, située sur le Dragan, pouvant être complétée par d'autres installations plus petites sur certaines rivières du bassin du Crisul Repede et du Somes supérieur, devra coopérer avec une ou deux grandes centrales thermiques situées dans les bassins carbonifères de ces régions.

En ce qui concerne le centre de la Transylvanie, aussi longtemps qu'existera le gaz naturel, on ne poura pas produire l'énergie nécessaire meilleur marché qu'avec les centrales thermiques alimentées au gaz.

La mise de fonds demandée par les centrales citées sera très grande et ne pourra être faite (à l'exception de celle de Scropoasa) que lorsque les conditions économiques du pays le permettront et lorsque le marché sera déjà préparé par les moteurs à combustion interne ou par les centrales thermiques.

Une autre source très intéressante de courant hydroélectrique est l'énergie qui resultera de la canalisation, pour les rendre navigables, des principales rivières de la Roumanie. Le coût de ces

travaux est énorme et en disproportion avec l'état financier actuel de la Roumanie.

En résumé le problème des solutions thermiques et hydrauliques en Roumanie est résolu par la collaboration des deux sources, en commençant par la création de grandes centrales thermiques qui seront allégées, quand la situation économique le permettra, par des centrales hydrauliques là où ces travaux ne seront pas trop chers. En ce qui concerne l'alimentation en énergie des localités excentriques, les moteurs à combustion interne pouront satisfaire les demandes jusqu'à plusieurs milliers de chevaux. On peut voir sur la carte ci-jointe la répartition des consommateurs d'énergie avec les puissances installées suivant la nature de la source d'énergie. Sur la même carte a été marqué schématiquement le réseau de centrales thermiques et hydrauliques qui devront être installées, de même que le réseau principal de distribution et leurs liaisons.

Les centrales thermiques, à l'exception de celles installées dans les régions des gaz naturels ou de pétrole, utiliseront de préférence le lignite, combustible bon marché situé à proximité des centrales; il est recommandable de n'utiliser que les produits de distillation à basse température et en premier lieu les déchets pulvérisés du coke et le surplus de gaz débenzolés.

En dehors des consommateurs d'énergie des centrales citées plus haut : les industries, l'éclairage des villes, etc., il y a un autre grand consommateur d'énergie: les chemins de fer. Ceux-ci, jusqu'à leur électrification, doivent transporter leur réserve d'énergie et il reste à voir dans quelle mesure l'électrification est plus avantageuse que l'utilisation des locomotives à vapeur. Il est bien entendu qu'il est dans l'intérêt des chemins de fer de n'utiliser que des combustibles supérieurs, en transportant une énergie aussi grande que possible dans un volume aussi petit que possible, et les lignites actuels présentent le grand désavantage de contenir un grand pourcentage de cendres et d'eau représentant un poids mort important. L'emploi du coke de lignite est absolument indiqué étant un produit de grand pouvoir calorifique, sans eau, ayant un pouvoir radiant supérieur à celui d'un charbon de valeur égale et une combustion régulière sans fumée.

En résumé nous voyons que pour la Roumanie une utilisation rationnelle des lignites est tout-à-fait nécessaire, ce pays ayant d'énormes réserves de lignites. Soit par séchage et briquettage, soit par distillation à basse température, on obtient des combustibles supérieurs autant pour les industries qui se procurent elles-mêmes l'énergie ou ont besoin de leur pouvoir calorifique que pour les

chemins de fer et pour les centrales thermoélectriques, centrales qui sont la solution la plus indiquée de la situation actuelle de la Roumanie pour la création d'énergie en grandes quantités et à bon marché.

La distillation à basse température présente un avantage sur le simple séchage des lignites, par le fait que le coke obtenu est un combustible supérieur au lignite séché et que l'on obtient en plus une série de produits qui peuvent être mieux mis en valeur; ainsi une partie des goudrons peut être utilisée à la fabrication du brai nécessaire au briquettage, une partie servira à la fabrication des huiles de graissage. La paraffine a son emploi connu.

La fabrication des briquettes de coke de lignite présente encore un avantage, celui de pouvoir remplacer progressivement le bois de chauffage dans les emplois domestiques en évitant ainsi d'énormes pertes pour l'économie nationale par la combustion irrationnelle du bois des forêts qui pourraient ainsi avoir une utilisation meilleure et servir à l'exportation.

RÉSUMÉ

Roumania has numerous lignite fields, and her reserves of this mineral situated both outside the crescent formed by the Carpathian mountains and in Transylvania, are of such importance that the study of its rational use is one of the chief problems of our country.

We have tried with satisfactory technical results the adaptation of fuel plants to the characteristic features of lignite, and its improvement by physical agents in order to obtain a superior quality.

It is, nevertheless, a fact that in a country like Roumania, which is a large oil and timber producer, lignite as fuel has powerful competitors. In such circumstances the lignite collieries must yield a maximum of profit, and we recommend low-temperature distillation as a means to this end. The Institute of Industrial Chemistry in Bucharest has experimented with this method, with very satisfactory results, and has obtained from some of the characteristic Roumanian lignite types a friable primary coke, containing 65 to 80 per cent. of the original calories of lignite. The tar thus obtained varied from 6·8 to 8 per cent., and the distilled gas, varying in quantity from 50 to 130 m^3, had 3,335 to 9,094 calories per cu. metre.

The primary coke has been transformed into briquettes. 97 per cent. of its binding material is lignite tar and only 3 per cent. oil-tar. Besides the question of rational use of lignite in Roumania there is the problem of the national energy which, in the present economic and financial conditions, must be solved. We recommend the building of large thermo-dynamic power stations with the most rational use of lignite and later on, according to the possibilities, the installation of hydraulic power-stations, which would work hand in hand with the former.

W.P.C.
COMITÉ NATIONAL ROUMAIN
CEHOSLOVACIA
POLONIA
UCRAINA
UNGARIA
IUGOSLAVIA
BULGARIA
400
2600
2600
3500
13
14700
70
25000
320
3000
5000
70
110
250
7000
840000
500
7600
5300
200
24000
1500
500
100
2500
330
5300
19000
9000
12000
36000
10000
20000
12000
PROBABLE COAL RESERVE
VALUED IN MILLION KWH
RESERVE PROBABLE DE CHARBON
EVALUÉE EN MILLIONS KWH
1 KWH = 2,75 Kgr. of coal
1 mm² = 100.000.000 KWH
Coal (Houille)
Brown coal (Charbon brun)
Inferior lignite

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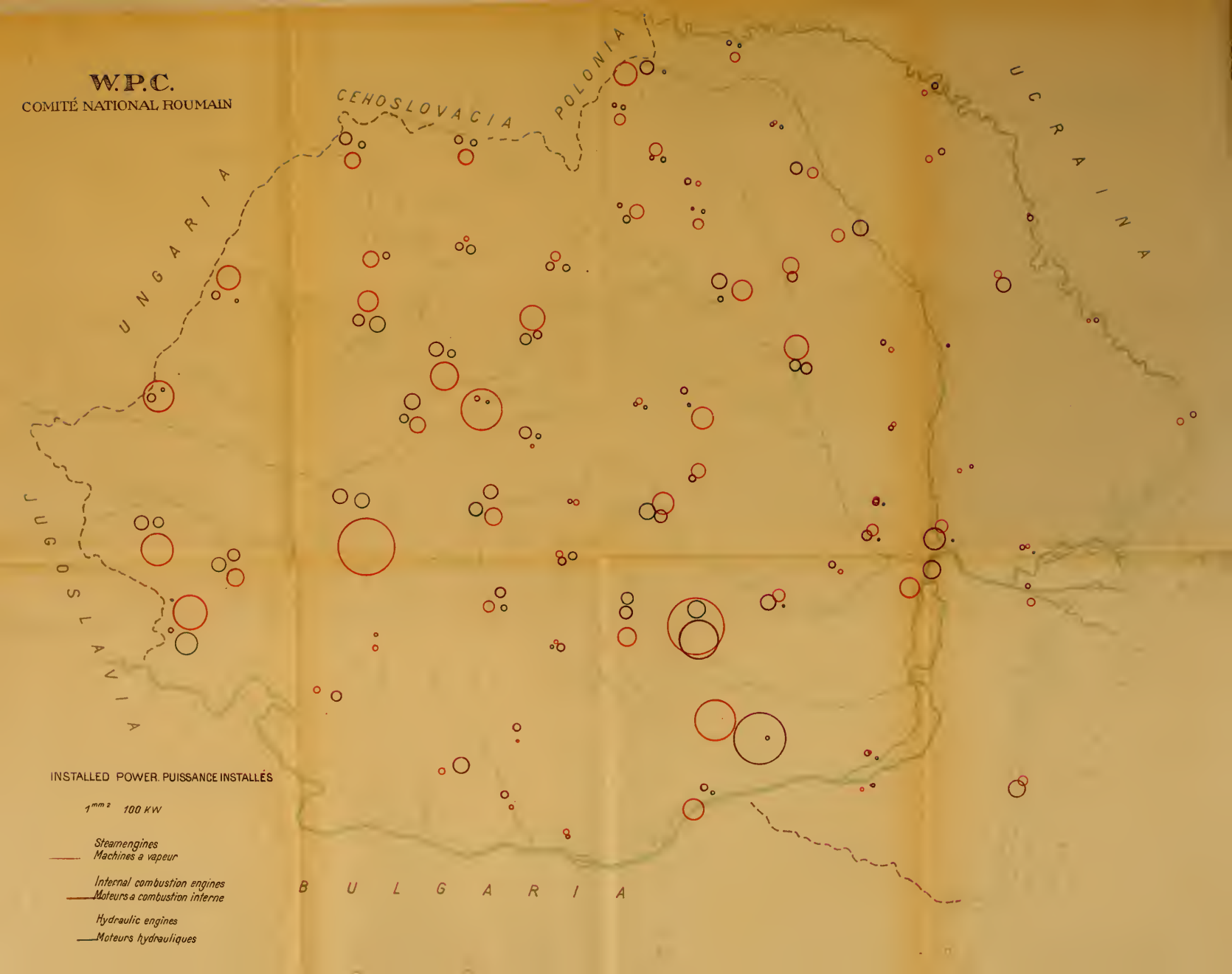
COMITÉ NATIONAL ROUMAIN

W.P.C.
COMITÉ NATIONAL ROUMAIN
CEHOSLOVACIA
POLONIA
UCRAINA
UNGARIA
IUGOSLAVIA
BULGARIA
MAREA NEAGRĂ
Thermo-electric power station
Centrale thermoélectrique
Hydro-electric power station
Centrale hydroélectrique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COMITÉ NATIONAL ROUMAIN
CEHOSLOVACIA
POLONIA
UCRAINA
UNGARIA
JUGOSLAVIA
BULGARIA
INSTALLED POWER. PUISSANCE INSTALLÉS
1mm² 100 KW
Steamengines
Machines a vapeur
Internal combustion engines
Moteurs a combustion interne
Hydraulic engines
Moteurs hydrauliques

TABLEAU No. 1

No. crt.	Provenance des échantillons.	Analyse immédiate				Pouvoir calorifique du lignite.	Résultats de la distillation.				Semi-coke.		No.
		Humidité. pour cent	Matières volatiles. pour cent	Coke. pour cent	Cendres. pour cent	Carbone fixe. pour cent		Goudron. pour cent	Eau. pour cent	Semi-coke. pour cent	Gaz. pour cent	Cendres. pour cent	Pouvoir calorifique.	
1	Lignite "Sinersig" Timis-Torontal	45,22	21,55	33,23	9,92	23,31	2615	4,20	51,35	34,43	10,02	28,81	5695	1
2	,, "Cârpa" ,, ,, ...	19,06	24,28	56,66	36,43	20,23	2301	3,00	26,32	57,33	13,15	62,32	2986	2
3	,, "Izvorul Anestilor" Mehedinti	23,51	31,83	44,66	20,31	24,35	2751	3,85	41,20	45,92	9,03	44,23	4295	3
4	,, "Rovinari" Jud. Gorj	30,21	33,25	36,54	10,23	26,31	3265	3,10	40,25	38,52	18,13	26,74	5963	4
5	,, "Schitu Golesti" Mina Poenari Muscel ...	23,10	36,32	40,58	10,15	30,43	4326	5,20	36,12	43,35	15,33	23,59	6228	5
6	,, "Sotânga-Doicesti" Dâmbovita	28,10	35,83	36,07	8,52	27,55	5015	5,10	39,62	40,36	15,02	21,16	6119	6
7	,, "Ojasca" Jud. Buzau	20,81	37,52	41,67	13,02	28,65	3826	4,82	31,56	46,20	17,42	28,18	5844	7
8	Charbon brun "Darmanesti" Bacau	12,10	36,15	51,75	11,70	40,05	5231	4,95	22,63	54,21	18,21	21,59	6382	8
9	,, ,, "Surduc," Salajul	9,28	37,52	53,20	10,50	42,50	5623	5,90	19,45	57,30	17,35	18,32	6642	9
10	,, ,, "Tihau" ,, ...	10,85	10,85	54,90	12,02	42,88	5130	4,36	19,28	58,70	17,66	20,47	6471	10
11	,, ,, "Tebea-Brad" Hunedoara	20,64	33,86	45,50	7,56	36,94	4605	3,85	32,21	49,30	14,64	15,34	6891	11
12	,, ,, "Petrosani-Vulcan" M.C.Couche I. ...	2,76	37,74	59,50	9,80	49,70	6521	11,80	10,28	62,85	15,07	15,59	6871	12
13	,, ,, Idem II.	2,65	38,55	58,80	20,34	38,46	5302	13,10	9,85	62,23	14,82	32,68	5480	13
14	,, ,, "Petrosani" Mina Est Couche III. ...	4,12	35,38	60,50	15,60	44,90	5881	10,50	11,85	63,32	14,33	24,63	6135	14
15	,, ,, Mina Vest 4	5,64	38,16	56,20	9,18	47,02	6108	8,53	14,12	60,80	16,55	15,45	6882	15
16	,, ,, ,, Vest 5	3,86	36,14	59,00	16,50	42,50	5838	10,48	9,65	62,06	17,81	26,61	5974	16
17	,, ,, ,, Vest 6	6,20	33,10	6,70	15,94	44,76	5723	8,10	13,15	63,21	15,54	25,21	6088	17
18	,, ,, ,, Est 7	5,34	37,66	57,00	6,30	50,70	6523	8,50	12,28	60,42	18,80	10,43	7291	18
19	,, ,, ,, Est 8	3,81	38,19	58,00	17,18	40,82	5596	10,45	11,23	61,87	16,45	27,76	5880	19
20	,, ,, ,, Est 9	3,34	44,16	52,50	25,20	27,30	5182	19,75	10,23	53,88	16,14	46,77	4333	20
21	,, ,, ,, Petrilla Couche 10	4,10	35,40	60,50	12,24	48,26	6105	10,15	10,80	62,27	16,78	19,66	6540	21
22	,, ,, ,, ,, 11	4,64	35,66	59,70	13,56	46,14	5893	9,35	12,15	62,18	16,32	21,80	6365	22
23	,, ,, ,, ,, 12	5,14	35,86	59,80	9,86	49,16	6302	7,50	13,11	60,90	18,49	20,34	7977	23
24	,, ,, ,, Vest Couche 13	5,72	35,28	59,00	6,80	52,20	6582	7,15	14,23	61,50	17,12	11,06	7240	24
25	,, ,, ,, Est ,, 14	4,84	32,66	62,50	16,86	45,64	5390	8,54	11,82	64,45	15,19	26,16	6010	25
26	,, ,, ,, Vest ,, 15	5,10	31,90	63,00	15,72	47,28	5573	7,10	10,55	64,38	17,97	24,41	6153	26
27	,, ,, ,, ,, ,, 17	3,15	34,35	62,50	20,92	41,58	5320	8,50	10,15	64,20	17,15	32,58	5488	27
28	,, ,, ,, ,, ,, 18	4,10	37,70	58,20	7,42	50,78	6495	12,10	10,25	60,38	17,27	12,39	7131	28
29	,, ,, "Petrosani" Mélange de l'installation du traitement mécanique	3,20	37,30	59,50	20,32	39,18	5368	9,32	10,01	61,53	19,14	35,57	5406	29
30	,, ,, "Lonea" Couche 3	5,30	40,20	54,50	13,22	41,28	6021	9,50	14,32	56,68	19,50	23,33	6241	30
31	,, ,, ,, ,, 4	5,14	34,36	60,50	16,10	43,40	5630	7,15	12,82	62,68	17,35	27,28	5919	31
32	,, ,, ,, ,, 5	4,82	40,98	54,20	10,76	43,44	6301	12,51	10,39	58,85	18,25	18,92	6600	32
33	,, ,, "Lupeni" ,, principale O ...	3,21	36,79	60,00	6,30	53,70	7185	13,20	9,52	62,15	15,13	10,14	7314	33
34	,, ,, ,, ,, 1	2,56	37,74	60,00	12,63	47,37	6502	12,85	6,82	62,41	17,92	20,27	6490	34
35	,, ,, ,, ,, 2	2,32	38,18	59,50	9,70	49,80	6858	12,95	8,12	61,10	17,83	15,88	6845	35
36	,, ,, ,, ,, 3	1,83	42,68	55,57	5,68	49,89	7760	15,21	6,30	62,84	15,65	10,07	7620	36
37	,, ,, ,, ,, 5	2,10	36,92	60,98	10,60	50,38	6861	13,15	7,40	63,18	16,27	16,77	6775	37
38	,, ,, ,, ,, 7	1,82	36,15	62,03	12,37	49,66	6182	11,75	6,90	65,21	16,14	18,96	6597	38
39	,, ,, ,, Mélange de l'installation de lavage	3,81	38,26	57,93	7,61	50,32	6963	13,20	8,15	60,58	17,97	12,54	7119	39

TABLEAU No. 2

RÉSULTATS ANALYTIQUES DE 4 ECHANTILLONS DE CHARBON SOUMIS À LA DISTILLATION

Spécification des échantillons.	Résultats rapportés au charbon naturel.											Résultats rapportés à la substance combustible.							
	Composition générale.			Composition élémentaire.					Transformation.	Substances combustibles.		Pouvoir cal. inf.	Composition élémentaire.					Substances combustibles.		Pouvoir calorifique.
	Eau pour cent	Cendres pour cent	Subst. combst. pour cent	C %	H %	S %	N %	O %	Coke pour cent	Carbon fixe pour cent	Mat. volat. pour cent	Calories par kg.	C %	H %	S %	N %	O %	Charbon fixe pour cent	Matières volatiles pour cent	Calories par kg.
Jidava-Pescareasca	19,15	10,90	69,95	54,13	4,93	0,67	0,70	9,52	49,52	38,42	31,53	4114,57	77,37	7,04	0,95	1,00	13,63	54,92	45,08	5882,1
Comanesti-Vermesti.	12,03	14,04	73,93	54,46	3,66	1,88	1,43	10,50	54,65	40,61	33,32	5007,69	76,36	4,95	2,54	1,93	14,22	54,25	45,75	6773,5
Lupeni	2,82	27,75	69,43	55,62	4,30	2,19	1,75	5,57	66,79	39,04	30,39	5455,13	80,10	6,19	3,15	2,52	8,04	56,22	43,78	7858,4
Pralea	43,99	14,45	41,56	24,56	2,10	0,38	0,77	13,75	32,22	17,77	23,79	2001,28	59,09	5,05	0,91	1,85	33,10	42,75	57,25	4815,39

A10—To follow Table 1

TABLEAU No. 3

PRODUITS DE DISTILLATION EXPRIMÉS EN GRAMMES ET CM³ ET RAPPORTÉS À CENT GRAMMES DE LIGNITE

Spécification des échantillons de lignite.	Distillation dans la cornue d'aluminium jusqu'à 500° et sans vapeur d'eau.				Distillation dans la cornue d'aluminium jusqu'à 50° et avec vapeur d'eau.				Distillation jusqu'à 500° dans le four rotatif.			
	Coke primaire pour cent	Goudrons primaires. pour cent	Gaz primaires. pour cent	Eau. pour cent	Coke primaire. pour cent	Goudrons primaires. pour cent	Gaz primaires. pour cent	Eau. pour cent	Coke primaire. pour cent	Goudrons primaires. pour cent	Gaz primaires. pour cent	Eau. pour cent
	g	g	cm.	g	g	g	cm.	g	g	g	cm.	g
Jidava-Pescareasca	50–55	6,5–7	8800–9500	27,0	53–54	7–7	9000–9500	—	53–55	6,5–7	9900–10000	27,0-27,1
Comanesti-Vermesti.	63,1–64	5,8–6	8000–8500	22,0	64–65	6,0–6,1	8000–8210	—	63–65	6,0–6,2	8700– 9500	22–22,1
Lupeni	77,9–78,4	8,3–8,4	4500–5000	8,42-8,45	78–78,45	8,39–8,49	4700–4900	—	75–77	8,5–8,8	4600– 5000	8,5–8,9
Pralea	34–36	3,5–3,8	7700–8000	50,1-50,2	35,5–36	3,8–3,9	7700–7800	—	35–37	3,6–3,9	7900– 8000	50,0

UTILISATION OF LOW-GRADE FUELS IN U.S.S.R.

STATE THERMO-TECHNICAL RESEARCH INSTITUTE, MOSCOW

PROF. L. K. RAMZIN

*Paper No. A*11

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PARAFFIN MAZOUT

ZUSAMMENFASSUNG

INTRODUCTION

The U.S.S.R. has always consumed low-grade fuel in quantities. It is not astonishing, therefore, that the problem of low-grade fuel combustion should constantly have occupied the attention of Russian combustion engineers.

Firewood ranks one of the first in the Fuel Balance of the Republic. *Peat* is the second variety of low-grade fuel that has obtained a wide use within the U.S.S.R. Noteworthy achievements have been attained in peat combustion, as discussed in a separate paper.

Although *Mazout* belongs to the very highest grade fuels, considerable difficulties, both as regards transportation and combustion, were experienced with a special kind of the latter, namely, paraffin mazout. Accordingly, the Thermo-Technical Institute were commissioned by the Grozni Oil Trust to endeavour to remove the drawbacks. The experiments on the combustion of paraffin and tarry mazouts have led to a complete solution of the problem, at

the same time helping to elucidate a series of general questions pertaining to oil fuel combustion.

Anthracite culms also belong to low-grade fuels which can be used on a large scale, because culm is always accumulating at the mines. At the same time, culm has hardly been made use of at all until recently. Below we intend to describe the results achieved in burning culm, as well as *anthracite rice* on mechanical chain grates.

Lastly we shall deal with *brown coals* of high ash contents, discussing the results achieved in combustion on chain grates. The combustion of pulverised anthracite culm and brown coals will be discussed in a separate paper.

Space limitation precludes a discussion of a whole series of other low grade fuels such as tan bark, peel of sunflower seed, sawdust, etc., which are also used in the U.S.S.R., but do not present any general interest.

When comparing and valuing individual furnaces and fuels, we intend making use of the methods expounded in another of my papers bearing on the combustion of pulverised fuel in the U.S.S.R. So the efficiency value of the furnace is represented by the magnitude :—

$$\eta_f = 100 - (q_2)_{150} - q_3 - q_4 \text{ per cent.}$$

where $(q_2)_{150}$ is loss with flue gases, the difference between gas and air temperature being : $T - t = 150°C.$;

q_3 loss due to incomplete chemical combustion.

q_4 loss due to mechanical incompleteness of combustion which includes :—

q_s loss due to the combustible falling through grate-bars, *i.e.*, siftings.

q_a heat loss due to unconsumed combustible in ash and clinker.

q_c heat loss with flue dust.

Thus, $q_4 = q_s + q_a + q_c$.

The magnitude of $\eta_{150} = \eta_f - 3$ stands for comparative efficiency of generating unit, *i.e.*, is reduced to the difference $T - t = 150°C.$, with radiation loss : $q_5 = 3$ per cent.

WOOD FUEL

Flat Grates

Although firewood and wood refuse are usually classed as belonging to low-grade fuels, firewood proves favourable for economic combustion as, owing to its low ash content and the large size of blocks, the mechanical losses of this kind of fuel are reduced to a minimum. The drawback, due to high moisture, consists mainly in a somewhat

increased volume of gases per unit of liberated heat, and consequently also in somewhat increased losses with flue gases. This latter slight drawback of firewood is compensated by the former advantage. As it is, firewood proves objectionable only on account of its extreme bulkiness, consequent on its slight thermal density, *i.e.*, heating value per unit of volume. The handling of firewood in large plants is therefore considerably impeded, while at the same time a large staff is required for its handling.

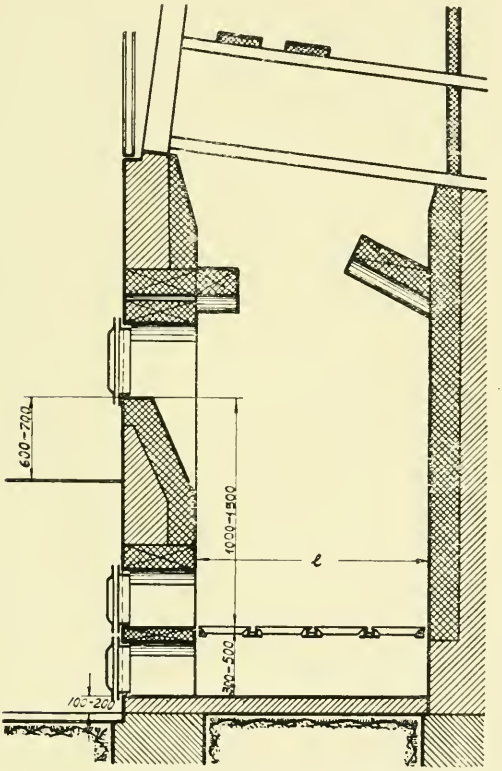

Fig. 1. Firewood furnace with lowered grate and raised fire-doors.

Up to the present two types of furnaces have mainly been used in the U.S.S.R., *viz.*, flat grates and shaft type furnaces.

As is well known, the fundamental drawback of a flat grate consists in an extremely uneven rate of combustion with regard to time, since every opening of the fire-doors for charging the furnace immediately interferes with the furnace work, causing a critical downfall of

combustion rate and simultaneously a large decrease of efficiency through the admittance of useless excess of air.

For eliminating these two drawbacks of a hand-fired stoker, Russian combustion engineers have been making use of the two following means :—

(*a*) The use of forced draft, which to a great extent eliminates defects due to opening the furnace doors and enables us to maintain a steadier combustion process. The introduction of forced draft permits a steady combustion of firewood containing up to 40 per cent. moisture.

(*b*) The use of furnace with lowered grate and elevated fire-doors of type illustrated on Fig. 1. This design makes use of the so called self-draft of the furnace, and reduces to a minimum the inflow of cold air, otherwise liberally admitted while opening the fire-doors for feeding. Therefore, having a determined suction of air at the level of the grate—3–4 mm. water column—this suction gradually decreases for higher levels until a level with excess pressure is ultimately reached. Now, by locating the fire-doors some 1–1·5 m. above the grate, we are able to obtain a suction of 1–1·5 m. less than when arranging them at the grate, because, assuming the suction at the grate to be 3 mm., this suction will not exceed 2–1·5 mm. at the fire-doors; this greatly decreases a wasteful inflow of cold air when opening the fire-doors, and besides allows the fuel-bed to be of sufficient thickness for maintaining a steady process of combustion.

Flat grates with blower fans or those with raised fire-doors afford full possibilities for an economical and steady combustion of fuel with about 45 per cent. and upwards of moisture.

The main advantage of the flat grate, which has already acquired a vast field of application, consists in its extreme simplicity and cheapness and also in its flexibility in exploitation. The disadvantages may be summed up as follows : limited capacity permitting a maximal evaporation of but 25 to 30 Kg. per sq. metre of boiler heating surface per hour ; lowered efficiency $\eta_f \sim 86$ per cent.; excessive labour required,—for no more than 500–600 Kg. consumed firewood per hour can be estimated for the output of a fireman; therefore, such furnaces may be applied in small plants only. The fundamental characteristics of furnaces of such type are given in Table I.

Shaft Furnaces

Shaft furnaces, which have long been applied in the U.S.S.R. for firewood combustion, are represented by several thoroughly

TABLE I

CHARACTERISTICS OF WOOD FUEL FURNACE EFFICIENCY

	Type of furnace.	Wf Maximum.	Q/R	Q/V	α_c	$(q_2)_{150}$	q_3	q_4	ηf	η_{150}	Maximum l	Maximum* D/H
		Per cent.	Thous. cal. / m.²h.	Thous. cal. / m.³h.	—	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	m	Kg./m.²h
1	Ordinary grate (improved)	35–40	1,000	350	1·8	11·2	2	1	85·8	83·8	2·2	30
2	Inclined shaft	45–50	1,200	350	1·4	9·1	2	1	87·9	84·9	2·5	40
3	Vertical shaft ...	50–55	3,000	350	1·4	9·1	2	1	87·9	84·9	1·5	40
4	Chips on chain grate ...	45 and>	900	290	1·4	9·0	0·5	2	88·5	85·5	4·6	48–72

NOTE : * With $\frac{\text{boiler heating surface}}{\text{internal width of boiler setting}} = 100 \frac{\text{sq. m.}}{\text{m}}$; $\eta = \eta_{150}$ and $l = l_{max.}$

All estimates of losses and ηf made for firewood with $wf = 30$ per cent.

elaborated and well-tested designs. As may be seen from Table I., these designs afford a very high rate of efficiency $\eta_f \sim 88$ per cent.

Shaft furnaces greatly facilitate the work of firemen, and also require a smaller number of the latter, because the output of a fireman in this instance increases to 900–1,300 Kg. of firewood consumed per hour. Complete steadiness of the combustion stands also among the advantages of these designs, as no periodic charging interrupts the work of the furnace. One drawback of shaft furnaces is the considerable inertia of the furnace due to its containing a large volume of fuel, wherefore such furnaces cannot be used where necessity of frequent interruptions of work arises, and should only be installed in such plants where continuous work is carried on in two or more shifts. A second drawback of the shaft furnace consists in the necessity of varying the thickness of the fuel-bed by means of re-modelling the furnace to suit the particular requirements of a given kind of firewood.

Under average conditions shaft furnaces allow of a rate of evaporation up to $\frac{D}{H} \sim 40$ Kg./m.²h (Kg. per sq. metre of boiler heating surface per hour) as shown in Table I.

The following two main types of shaft furnaces are used in the U.S.S.R.:

(*a*) Those with inclined surface of fuel-bed (inclined grate stokers, as in Fig. 2). Practice has shown the limit of breadth, and consequently also the length of the log in such furnaces to be 1·5 to 1·8 m., since the upper supporting arch no more holds when these dimensions are exceeded. The limit length (L) of fuel-bed surface is 2·5 m., while lengths above 3 m. are prohibitive. The normal rate of heat liberation in such furnaces should be $\frac{Q}{R} = 1{,}200$ thousands cal./m.²h.; the suction in the furnace should not be below 5 mm., so that the the smoking from the upper door of shaft may be eliminated.

Furnaces of this type realise altogether reliable combustion of firewood with moisture up to 45 and even 50 per cent., thereby securing a high efficiency with small excess of air to the furnace. In record cases it was even possible to reduce the coefficient of air excess to 1·2–1·25, while combustion proved to be altogether complete, giving 16 to 16·5 per cent. of CO_2.

(*b*) Shaft furnaces with vertical surface of fuel-bed (Fig. 3) appear to be simpler in design, since they require a minimal amount of metal work and very simple setting.

The size of shaft is unlimited, so that firewood of any desired size may be burned. The shaft is charged with logs arranged to form a

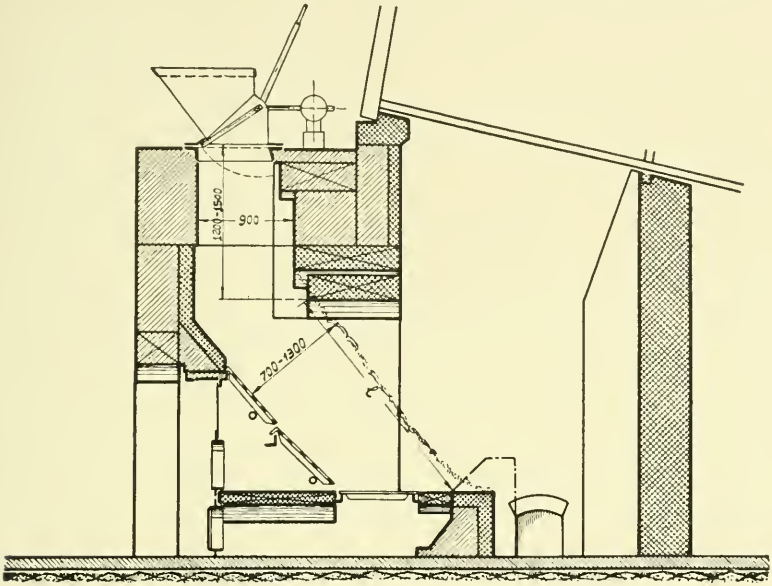

Fig. 2. Firewood shaft furnace with inclined combustion surface.

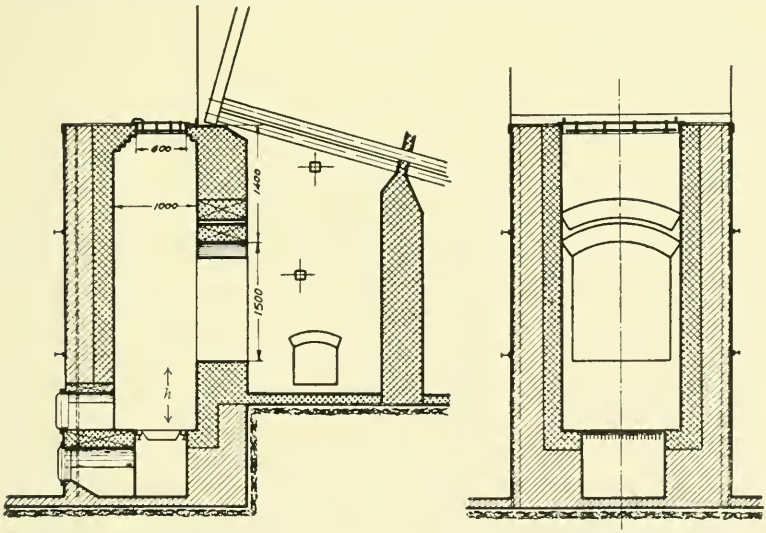

Fig. 3. Firewood shaft furnace with vertical combustion surface.

vertical column, so that the combustion faces the gas window, the latter determining the actual surface of the fuel-bed. A very

important structural element is to be found in the height "h" of lower part of shaft, which value is increased in inverse proportion to a respective decrease of firewood combustibility, *i.e.*, higher moisture contents, greater size of logs and less combustible kinds of fuel wood. The normal rate of heat liberation as calculated per sq. metre of actual surface of fuel-bed is figured at $\frac{Q}{R} = 3{,}000$, *i.e.*, about 3,000,000 cal./m.^{2}h.

In 1922 the writer designed and later built a shaft furnace for locomotive boilers where the rate of heat liberation per sq. metre of surface of fuel-bed reached as much as 20 to 25 mil. cal./m.^{2}h., though, of course, rather considerable losses due to waste with flue dust were again involved. As compared with the ordinary flat-grates, such a furnace gave as much as 15 to 25 per cent. economy. This furnace, with which more than 200 experimental runs were effected, gave a very high content of carbon dioxide, averaging 13 to 14 per cent., which must be considered a quite considerable figure for locomotive boilers. The efficiency of the boiler, when burning firewood with 38 per cent. moisture, went as far as 75–79 per cent.

In all firewood consuming furnaces, the combustion chamber should be calculated for a rate of heat liberation that would not exceed 300–400 thousand cal./m.^{3}h., so that noticeably incomplete combustion should be eliminated as far as possible.

Combustion of Chips on Grate Stokers

Despite the high efficiency of shaft furnaces, the latter fail to realise the available rate of evaporation to any value approaching 40 Kg./m.^{2}h. Further, they require a large staff for attending to the boiler house, hauling wood and charging the furnace. Such furnaces also call for availability of firewood of uniform length, while the combustion of wood refuse assuming a varying and irregular form (such as branches, slabs, laths, etc.) is greatly obstructed.

The erection of rather considerable installations using wood fuel for a Paper Trust in the Central Industrial Region of U.S.S.R. induced the latter, jointly with the Thermo-Technical Institute, to seek a system so that wood fuel could be efficiently consumed in powerful plants with a capacity of 10–15,000 kW. and more. It was decided to make use of fuel wood split into chips by means of

chopping machines just as is done in the cellulose industry, rather than burn blocks of timber.

The Thermo-Technical Institute has worked out the designs of such plants, and has carried out a series of experiments both at its own experimental station and at the paper mill "Sokol," belonging to the aforesaid Trust.

The method adopted provides a wood-chopping machine of the type commonly employed in the cellulose industry. By means of this contrivance, logs are reduced to chips of an average size of 50 × 30 × 5 mm., with the power consumption about 7·5 kWh. per ton of chips.

Since it is quite possible to subject whole trunks to chopping, and thereby eliminate expenditure on sawing and splitting, we find that the cost of chip-fuel is practically the same as that of firewood, since the crushing of the former involves no extra expenditure.

Chain grates with sectional air distribution were selected for the purpose of the experiments in the Boiler Laboratory of the Thermo-Technical Institute, which were conducted on a Babcock & Wilcox chain grate (12 m.²) located under a Garbe-Krupp vertical water-tube boiler (300 m.²), while the main series of experiments at the paper mill "Sokol" was carried out on a chain grate with sectional forced draft constructed by the Bamag works (6·5 m.²) under a horizontal water-tube boiler of Babcock & Wilcox where H = 340 m.². A layout of the installation at the mill "Sokol," where the main experiments were conducted, is given in Fig. 4. The work was performed on chips carrying 26·5–43·2 per cent. moisture with pre-heated air at a temperature of 150°C. when entering under the grate. The main results of these tests are summed up in Table II.

As may be seen from this table the coefficient of excess air behind the boiler remained at normal loads $\alpha_c \sim 1{\cdot}4$ (40 per cent. of excess air) while losses due to chemical incompleteness of combustion q_3 appeared raised, owing to insufficient volume of the available combustion chamber. Experimental evidence shows that for attaining complete combustion $\frac{Q}{V}$ should not be estimated above 280–300 thousands cal./m.³h. As regards the rate of heat liberation $\frac{Q}{R}$ being raised (as may be seen from Table II.) to a value exceeding the order of 900 thousand cal./m.²h., the mechanical losses, mainly due to escape with flue dust, begin to increase rapidly, attaining considerably high magnitudes at high rates of combustion.

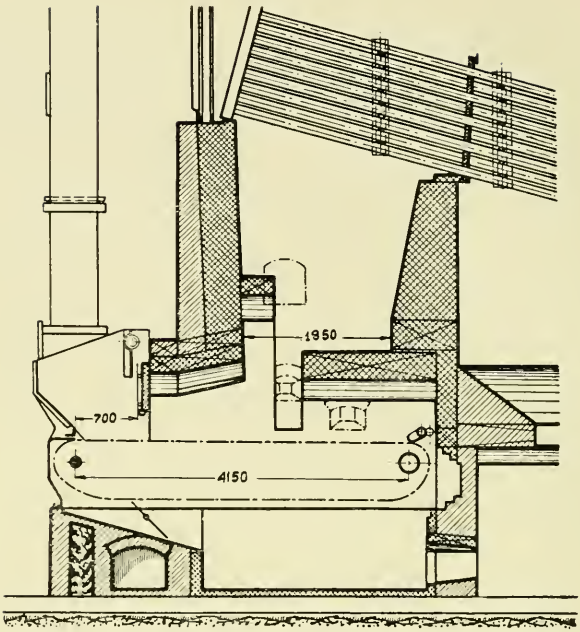

Fig. 4. Installation for chip combustion at the "Sokol" Mill (chain grate with sectional hot blast).

TABLE II

THE COMBUSTION OF CHIPS ON A CHAIN GRATE

Rate of heat liberation per unit of grate area	Q/R	800	900	1,000	1,100	1,200	thous. cal./m.^{2}h
Rate of heat liberation per unit furnace volume	Q/V	290	330	365	400	440	thous. cal./m.^{3}h
Coefficient of air excess behind boiler	α_c	1·75	1·58	1·44	1·31	1·20	—
Loss due to flue gases with $T - t = 150$°C.	$(q_2)_{150}$	11·1	10·0	9·1	8·3	7·4	per cent.
Loss due to chemical incompleteness of combustion	q_3	0·2	1·5	2·6	3·3	4·0	per cent.
Loss due to siftings ...	q_s	0·1	0·1	0·1	0·1	0·1	per cent.
Loss due to waste with flue dust	q_c	0	1·4	3·2	5·4	8·8	per cent.
Sum total of mechanical losses	q_4	0·1	1·5	3·3	5·5	8·9	per cent.
Radiation loss	q_5	3·5	3·2	3·0	2·8	2·6	per cent.
Comparative efficiency with $T - t = 150$°C.	ηf	85·1	83·8	82·0	80·1	77·1	per cent.

For instance, with 1,200 thousand cal./m.²h. losses with flue dust figure as high as 8·8 per cent. From the foregoing it is clear that the combustion of chip firewood requires a normal rate of combustion $\frac{Q}{R}$ of the order of 900 thousand cal./m.²h. which reduces mechanical losses to about 1·5 per cent. On account of the unavoidable increase of losses under ordinary exploitation, the mechanical losses in the table are increased up to 2·0 per cent., showing the characteristics of furnaces under working conditions.

It may be stated that the combustion of chips on a chain grate is very economical, yielding a comparative furnace efficiency of no less than 88·5 per cent. Under test conditions the efficiency may be raised up to, say, 90 per cent. on account of a further decrease of the excess of air, as well as due to a reduction of losses connected with both chemical and mechanical incompleteness of combustion.

Thus, if $T - t$ be equal to 150°C., plants fitted with economizers may have a very high rate of efficiency, *viz.*, 85–87 per cent.

The combustion of firewood in the form of chips has entirely solved, both from a technical and economic standpoint, the problem of wood-fuel combustion in the largest power plants. Moreover, the turning of wood pulp into chips will present an excellent opportunity of mastering the combustion of most varied kinds of wood refuse, *e.g.*, branches, the refuse of sawmills and that of other wood-works, since, when worked over by means of choppers and turned into chips, such material, varied as it is, may be converted into uniform fuel, suitable both for transport and combustion.

It is considered that this method of firewood combustion, elaborated by the Thermo-Technical Institute jointly with the Central Paper Trust, will soon conquer a vast field of opportunities for practical application, due to its obvious advantages and economy in use.

Thus, the problem of firewood combustion in the U.S.S.R. is now entirely solved with regard to both small and middle-size power plants as well as for the largest power stations, in which instance the efficiency of wood combustion usually exceeds that of the combustion of coal.

The above considerations justify our fundamental conclusion that firewood, so far from being second-rate fuel, presents an excellent type of combustible material allowing a high degree of combustion efficiency.

COMBUSTION OF LOW-GRADE COALS ON CHAIN-GRATE STOKERS

As seen above, the chain grate has been very successfully applied to the combustion of chip firewood ; the application of the chain grate to the combustion of peat has proved equally successful in the U.S.S.R. In this section, we give data on the combustion of impure brown coals and small sizes of anthracite on a chain grate.

Brown Coal of the Sub-Moscow Region

The problem of the combustion of Sub-Moscow brown coal on chain grates has become important since the erection near Moscow of the Kashira Generating Plant working on that coal. The fundamental characteristics of Sub-Moscow coal are given in Table III., based on the combustion of fines containing about 35 per cent. of slack of sizes below 5 mm., 34 per cent. of lumps 5 to 18 mm. in size and 31 per cent. of lumps of 18–50 mm.; at the same time the fuel investigated contained nearly 14 per cent. of very small pieces of the size of 2 mm. The efficient combustion of this fuel presents

TABLE III (in three parts)

No. of item	Design of Chain Grate.	Kind of blast.	FUEL. Description.	W^f Per cent.	A^d Per cent.	V^c Per cent.
1	Babcock & Wilcox	Cold	Sub-Moscow			
2	with revolver bars	Hot	brown coal	33	31·5	45
3	without sections	,,	fines			
4	$R = 1{\cdot}97 \times 3{\cdot}5 =$	,,				
5	6·9m.^{2}	,,				
6	Babcock & Wilcox	Cold	Bogoslov brown coal	33	15·0	42·5
7	with sectional	Cold	Tcheliabinsk	22	18	41·5
8	blast, 6 sections	Hot	brown coal	20	15·5	43·5
9		,,		20	15·5	43·5
10	$R = 2{\cdot}42 \times 5{\cdot}0 =$ 12·1 m.^{2}	Hot	Same—slack	20·5	19·8	40·0
11		Cold	Anthracite rice			
12		,,				
13		,,		4·0	18·2	4·8
14		,,				
15		Hot	Anthracite culm	9·5	19·9	4·8

Note : Individual losses and comparative efficiencies calculated in terms of net calorific value of fuel.

TABLE III—*continued*

FUEL.		Q/R	Q/V	α_c	HEAT BALANCE.				
Q_g^f	Q_n^f				$(q_2)_{150}$	q_3	q_s	q_a	q_c
Cal./ Kg.	Cal./ Kg.	thous. cal m.²h.	thous. cal m.³h.		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
2990	2670	650	335	2·87	13·9	0·5	4·3	14·2	7·9
		650	335	1·89	11·7	1·5	1·6	2·6	1·5
		900	460	1·69	10·4	2·1	1·8	2·8	3·9
		1150	590	1·55	8·9	2·5	1·9	3·5	10·9
		1400	720	1·42	6·5	2·8	2·0	6·0	29·6
3530	3195	568	215	1·6	9·5	1·2	6·0	2·0	4·0
4610	4300	880	330	1·65	8·9	1·3	5·5	2·2	2·0
4820	4505	850	320	1·42	8·3	1·6	0·9	2·9	0·4
		1040	395	1·35	7·9	2·3	1·3	2·4	0·5
4525	4225	780	295	1·36	7·3	1·1	4·6	1·7	5·2
6455	6330	520	210	1·34	6·5	0	3·1	9·1	1·4
		785	320	1·45	6·8	0	3·3	10·8	2·0
		870	350	1·33	6·4	0·6	3·7	7·9	2·2
		1090	440	1·44	6·7	0	3·0	10·8	2·4
5820	5680	875	330	2·02	5·9	0·6	23·6	16·6	6·6

TABLE III—*further continued*

HEAT BALANCE.			HEAT BALANCE, siftings lacking (q_s = 0).				
q_4	ηf	η_{150}	$(q_2)_{150}$	q_3	q_4	ηf	η_{150}
Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
26·4	59·2	56·2	14·5	0·5	23·1	61·9	58·9
5·7	81·1	78·1	11·9	1·5	4·2	82·4	79·4
8·5	79·0	76·0	10·6	2·1	6·8	80·5	77·5
16·3	72·3	69·3	9·1	2·5	14·7	73·7	70·7
37·6	53·1	50·1	6·6	2·8	36·4	54·2	51·2
12·0	77·3	74·3	10·1	1·3	6·4	82·2	79·2
9·7	80·1	77·1	9·4	1·4	4·4	84·8	81·8
4·2	85·9	82·9	8·4	1·6	3·3	86·7	83·7
4·2	85·6	82·6	8·0	2·3	2·9	86·8	83·8
11·5	80·1	77·1	7·7	1·1	7·2	84·0	81·0
13·6	79·9	76·9	6·7	0	10·8	82·5	79·5
16·1	77·1	74·1	7·0	0	13·3	79·7	76·7
13·8	79·2	76·2	6·7	0·6	10·5	82·2	79·2
16·2	77·1	74·1	6·9	0	13·6	79·5	76·5
46·8	46·7	43·7	7·7	0·8	30·4	61·1	58·1

great difficulties, its average moisture contents being about 33 per cent. as fired, while the ash content of dry coal was of $A^d = 31$ per cent.

After the Kashira Station had been erected, the combustion of Sub-Moscow coal was at first conducted on chain grates of different designs, cold air being blown in under the grate after the usual method. The best results obtained with the application of cold blast are given in Table III. Hence, the efficiency of combustion attained may be considered exceedingly low, owing to: (*a*) great air excess; (*b*) enormous losses through mechanical incompleteness of combustion, *viz.*, up to 26 per cent.; (*c*) low grate capacity, as the rate of combustion could not be raised above 650 thousand cal./m.^{2}h.; accordingly, the boiler efficiency amounted to 44 per cent. at best, the rate of evaporation being only 12 Kg. per m.^{2} per hour.

In order to improve the combustion of Sub-Moscow coal, the Kashira Station applied to the Thermo-Technical Institute, which suggested the combustion of Sub-Moscow coal using pre-heated air ; *i.e.*, with hot blast. Taking into account the lack of air pre-heaters, which were not available at the time, the Thermo-Technical Institute proposed a very simple but ingenious method of air pre-heating by mixing it up with a part of the flue gases evacuated from the combustion chamber. With that object one side of the boiler was joined to a small brick chamber communicating through a window with the combustion chamber, and through another with the external air, thus allowing regulation by means of shutters, the admission of both flue gases and air, thereby varying the temperature of the mixture. The mixture contained approximately 20 per cent. of gases and 80 per cent. of air and had a temperature up to 200°C. or less; the carbon dioxide content was about 2–2·5 per cent. This mixture was sucked in by a fan and blown under the grate. Thus the problem of obtaining hot blast of practically any desired temperature was solved by means of regulating the percentage of gases admixed. The experiment was conducted on an old Babcock and Wilcox chain grate 1·97 m. wide, with an active length of 3·5 m.; the grate area thus being R = 6·9 m.^{2}. This chain grate, fitted with revolver bars, was located under a horizontal Babcock and Wilcox water-tube boiler with a 302 m.^{2} heating surface. As seen in Fig. 5, the grate was arched with long rear and also front arches, providing for sufficient mixture and the requisite direction of the gas streams, so that the stratification of gases should be eliminated.

After application of the hot blast, the efficiency of the furnace had markedly improved, as seen from figures given in Table III.

The results quoted represent the average values obtained by the Thermo-Technical Institute from over 70 tests carried out at the Kashira State Station. In the first place, heat liberation has been raised to 1,400 thousand cal./m.²h., further increase being limited only by the capacity of the fan and, naturally, also by the furnace efficiency. The application of hot blast has markedly lowered the air excess and loss of combustible in clinker, having simultaneously reduced losses through falling between the grate bars (siftings) and waste with fuel dust, so that the mechanical losses have fallen

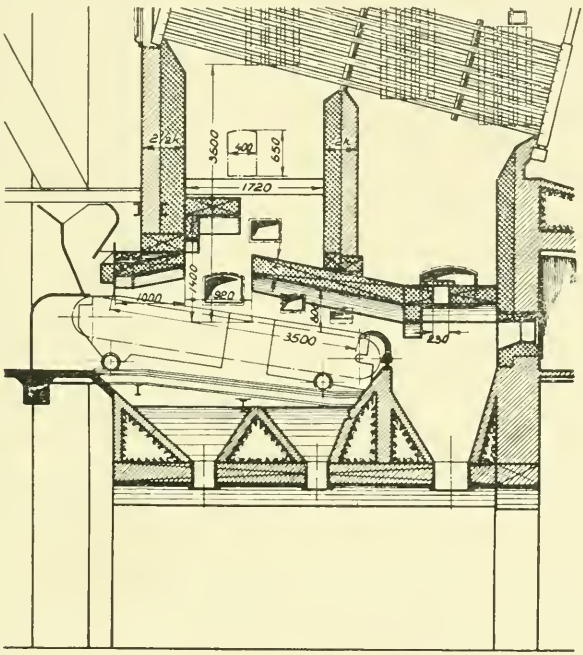

Fig. 5. Installation for combustion of Sub-Moscow brown coal on chain grate with hot blast.

from 26 per cent., as in the case of the cold blast, to 6–8 per cent. When hot blast was applied the efficiency of the boiler rose to 70 per cent. with simultaneous increase of steam evaporation to 22 Kg. which corresponds to heat liberation: $\frac{Q}{R} = 900$ thousand cal./m.²h.

The marked improvement of furnace efficiency after the adoption of hot blast is characterised by the figures of comparative efficiency, η_f, given in Table III., *viz.*: $\eta_f = 59$ per cent. for cold blast rises

to 81 per cent. for hot blast. As seen from Table III., the limit of efficiency of heat liberation per unit of grate area is $\frac{Q}{R} \cong 900$ thousand cal./m.²h.

A further rise of this magnitude involves a great increase of the losses, mostly with flue dust and partly also in clinker, which cause a considerable augmentation of mechanical losses of the furnace in spite of a continuous slow decrease of losses with flue gases owing to an uninterrupted fall of the air excess coefficient with the rise of the rate of combustion. Magnitude $\frac{Q}{V} \cong 250$ thousand cal./m³.h. should be considered the normal heat liberation per unit of furnace volume for Sub-Moscow coal in the case of a chain grate, since, with the increase of this magnitude the augmentation of losses through chemical incompleteness of combustion becomes perceptible.

Thus $\eta_{150} = 78$ per cent. for a generating unit with temperature of flue gases $\mathcal{T} \cong 175°C.$; at $T - t = 150°C.$

It is plain that the pre-heating of air at the expense of the above-mentioned mixing of gases, constitutes but a very primitive method, though, as we have seen, it has had a very considerable effect. The pre-heating of the air may, of course, be carried out more effectively in the usual way, by means of air pre-heaters.

As our numerous experiments and lengthy observations under usual working conditions have proved, the pre-heating temperature of 200°C. is altogether reliable and involves no trouble in the work of the chain grate, whereas a rise of the air temperature approximately above 220–250°C. causes a series of difficulties in operation, as, for instance, the ignition of lubrication and dust in different parts of the chain-grate mechanism, tending to prevent the regular work of the latter.

Thus, the use of hot blast, a rational construction of furnace with chain-grate stoker, and a regular regime of work have afforded the means of successfully solving the difficult problem of the combustion of Sub-Moscow coal, exceedingly low grade fuel as it is.

All further experiments on the combustion of Tcheliabinsk coal, anthracite rice and anthracite culm which are to be dealt with below, have been conducted in the Boiler Laboratory of the Thermo-Technical Institute under the Garbe boiler of Krupp's works with heating surface $H_b = 300$ m.² and over a Babcock & Wilcox chain grate stoker with sectional blast, 2·42 m. wide, 5 m. long, *i.e.*, with

grate area $R = 12{\cdot}1 \text{m.}^2$. The chain grate had 6 sections with cylindrical valves for the automatic removal of fines dropping through the chain.

Tcheliabinsk Brown Coal

The Tcheliabinsk brown coal belongs to the variety known as "Pechkohle," and is therefore classed as intermediate between brown coals and coals. It is, as seen in Table III., characterised by a moisture content of 20 per cent. and ash content, A^d — 15 or 20 per cent., calculated in terms of dry coal. The results given hereunder represent the average data of the combustion of two grades of Tcheliabinsk coal at the Experimental Station of the Thermo-Technical Institute, *viz.*:

(*a*) Run-of-mine containing lumps 50 to 0 mm. in size, part of which, *viz.*, 28 per cent., is constituted of slacks of under 6 mm. size.

(*b*) Slacks with 60 per cent. of pieces 5 mm. thick and downwards.

The fundamental conclusions drawn from the experimental tests are given in Table III. Here again an improvement of the furnace efficiency is seen after the adoption of hot blast ; while, in the case of cold blast, the relative efficiency of the furnace amounted to about 80 per cent., the adoption of hot blast resulted in raising the efficiency 86·0 per cent. This was attained owing to a reduction of excess air and was especially due to a decrease in the mechanical incompleteness of combustion.

As may be seen from test results, normal heat liberation per sq. metre per hour for chain grate stoker when burning Tcheliabinsk coals should be estimated at $Q/R \simeq 1{,}000$ thousand cal./m.²h., while the normal heat liberation per unit furnace volume should b $\frac{Q}{V} = 300$ thousand cal./m³.h. Here again the limit of the rate of combustion is mainly set by losses with flue dust, although the latter, with $\frac{Q}{R} \simeq 1{,}000$ thousand cal./m.²h. does not yet amount to much.

When burning Tcheliabinsk run-of-mine fines with hot blasts, the furnace relative efficiency fell to 80·0 per cent. by reason of losses due to waste with flue dust, and especially to siftings through the grate. With the provision of such a design of furnace as would reduce the latter loss to a minimum, the furnace efficiency even when burning Tcheliabinsk fines could be increased up to

84·0 per cent., as may be seen in Table III. The location of arches for combustion of Tcheliabinsk coal is shown in Fig. 6.

Anthracite Rice

Anthracite rice is small sorted anthracite, with lump-size of 6 to 12 mm. The experiments of the Thermo-Technical Institute dealing with the combustion of rice gave rather favourable results. With a rate of heat liberation of about 900 thousand cal./m².h. the efficiency of the furnace was $\eta_f = 79$ per cent.; should the waste of fuel through grate bars be only slight, this efficiency may be raised up to 82 per cent. The normal heat liberation per unit furnace volume should be assumed at $\frac{Q}{V} \cong 350$ thousands cal./m.³h., in which case chemically complete combustion is provided for.

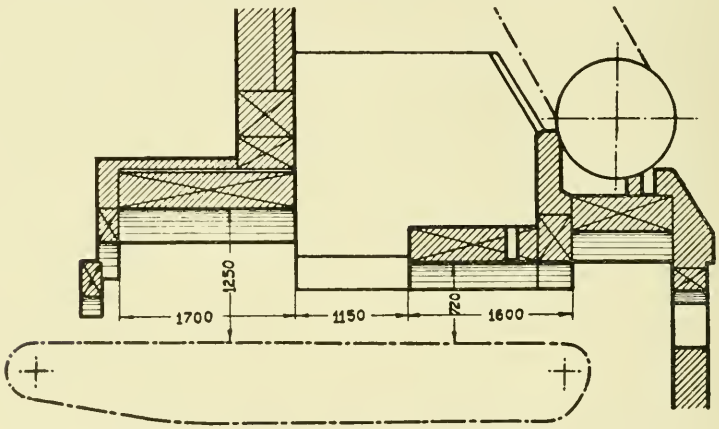

Fig. 6. Disposition of arches for burning Tcheliabinsk Brown coal.

The combustion of rice over the whole grate area was extremely even, and required hardly any labour on the part of the firemen, being performed almost automatically. The arch enclosure of chain grate is shown in Fig. 7. Thus, the combustion of anthracite rice on chain grates may be said to be altogether efficient.

Anthracite Culm

The results obtained with the combustion of culm over a chain grate were radically different. Notwithstanding repeated variations in the construction of front and rear arches, and despite hot blast and inforced cleaning of the fire, the effect was found to be far from satisfactory. The culm contained about 57 per cent. of pieces

below 2 mm., about 32 per cent. sizing from 2 to 5 mm. and 11 per cent. above 5 mm., while the normal upper limit of lump was established at 6 mm., culm being passed through a 6 mm. sieve.

As may be seen from Table III., culm combustion in the very first place necessitated considerable excess of air $\alpha_c = 2{\cdot}0$. Further, since our chain grate was found unsuitable for the combustion of fines, considerable losses through siftings were to be found, $q_3 = 23{\cdot}5$ per cent.; losses with combustible matter in clinker also reached a considerable figure, $q_a = 16{\cdot}5$ per cent., and finally, the efficiency was also greatly affected on account of waste with flue dust, $q_f = 6{\cdot}5$ per cent. Accordingly, the comparative furnace efficiency η_f equalled but 46·7 per cent. Even if

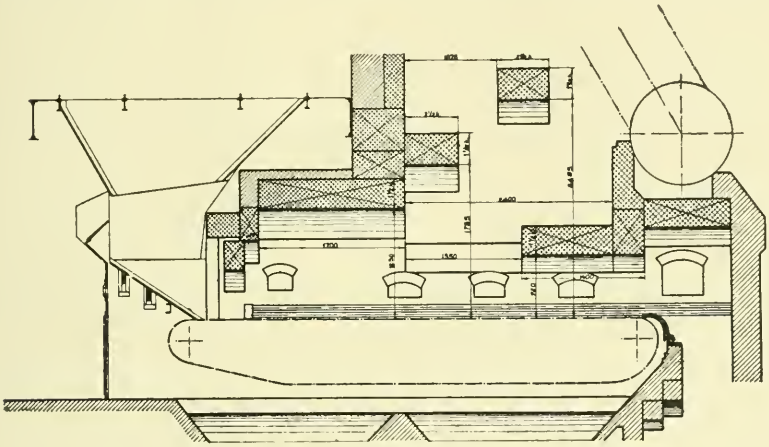

Fig. 7. Disposition of arches for burning anthracite rice.

we should exclude the siftings—a loss due to an inadequate design of chain—the comparative efficiency, as may be seen from Table III., will not be above 61 per cent. However, a reservation should be made to the effect that the heat liberation selected, $\frac{Q}{R} = 875$ thousand cal. m^2.h. appeared excessive, and a respective lowering would seem desirable since this might involve a reduction of losses.

Thus, no satisfactory results whatsoever were achieved with regard to the efficient combustion of culm over chain grates. The only economic means would seem to be provided by combustion in pulverised form.

General Deductions

Our survey of the combustion of low-grade fuels on chain grates

will be confined to the above five examples. Now we may make the following general deductions concerning the efficient combustion of non-caking and small-size fuels with high ash contents :—

(1) Hot blast proved highly effective for efficient combustion of moist brown coals. In this instance, a temperature of, say, 200°C. should be considered fully admissible as regards the chain grate.

(2) When burning the slack of non-caking fuels on a chain grate, losses through grate-bars prove rather considerable; therefore grates so designed as not to permit any considerable siftings should be selected. In the United States in 1927, the author observed that the Coxe chain grate gave very favourable results in this connection. This design reduces sifting losses to a minimum, while the blast sections are well sealed off—a feature meeting another of the fundamental requirements for the steady performance of a sectional chain grate.

(3) Still another loss for the same class of fuels is to be traced to waste with flue dust. This loss grows rapidly with a proportionate increase of heat liberation per unit of grate area.

(4) When burning slack of non-caking fuels, the limit of heat liberation is mainly set by waste with flue dust, the normal heat liberation of a chain grate being, for anthracite rice, brown coals, and chips, within the limits of about $\frac{Q}{R} = 800$ to 1,100, or is on the average of the order of 900 thousand cal./m.^{2}h.

(5) The heat liberation per unit of furnace volume $\frac{Q}{V}$ for brown coals, possessing a high content of volatile matters, should, when operating with a chain grate, be chosen within the range of 250–300 thousand cal./m.^{3}h., while this value may be raised to $\frac{Q}{V} \cong 350$ thousand cal./m.^{3}h. for anthracite. All at the same time a further increase of this value causes a marked chemical incompleteness of combustion.

(6) The methods heretofore applied for the combustion of anthracite culm containing a number of small pieces cannot be said to permit any degree of economy in combustion; hence, a conclusion as to the inefficiency of burning anthracite culm over chain grates seems implied. At any rate the existing designs prove wholly defective in this respect, so that the only efficient utilisation of anthracite culm would appear to consist in burning it in pulverised form. In this respect splendid results, which may be said to offer a

final solution of the problem, have been achieved in the U.S.S.R. But all data pertaining to the latter will be treated separately in a second paper, the present report endeavouring only to discuss different fuels and furnaces with regard to their comparative efficiencies.

PARAFFIN MAZOUT

In connection with the considerable development of oil production in the new fields of the Grozni district yielding chiefly paraffin oil, great quantities of paraffin mazout have begun to invade the Russian market. As this kind of mazout has a very high pour point, *viz.*, 35°C. and upwards, the consumers were naturally unprepared for the peculiarities of its utilisation, which caused considerable difficulties. In the first place the unloading of the tank cars presented great trouble, since the mazout usually arrived at its destination in a solidified state, assuming the consistency of a solid body when transported in tank cars in winter time; furthermore, certain inconvenience arose in connection with the pumping of the mazout from storage tanks to the boiler house, as well as within the latter; and lastly, the proper methods for its combustion were as yet insufficiently known.

At the request of the Grozni Oil Trust, the Thermo-Technical Institute has performed experimental investigation of both the unloading and carriage of paraffin mazout as well as on its combustion; the greater part of the experiments having been carried out in the Boiler Laboratory of the Institute with the exception of some experiments which have been conducted, also by the Institute, on board a Volga steamship. A detailed report of these investigations has already been published in Russian in the *Proceedings of the Thermo-Technical Institute*, therefore we shall confine this paper to some brief fundamental conclusions drawn from the data obtained during this investigation.

A thorough testing of over 100 samples of different mazouts has, in the first place, allowed us to carry out a study of their fundamental properties, which may be summed up as follows:—

Notwithstanding the commonly held opinion, the different varieties of mazout, all having a uniform specific gravity, give uniform ultimate analyses as well as calorific value, even though they may differ in pour point, which varies within the range of — 10° to + 40°C. depending on paraffin contents varying from 1 to 11 or 12 per cent.

As to the viscosity of different grades of mazout, the former at

35°C. is equal for both paraffin and paraffinless mazout, having the specific gravity of about 0·903, while at further rises of temperature the viscosity coefficient of paraffin mazouts becomes even lower than that of paraffinless samples. At temperatures of the order of 50°C., the viscosity varies within the limits of 3° to 4·5° Engler for all kinds of mazout.

A theoretical study of the subject and a subsequent checking of experimental results have proved the erroneousness of the widespread opinion regarding the influence of the viscosity of mazout upon the perfection of atomisation, since the fineness of the latter depends not on the viscosity but on the surface tension of the mazout.

With the rise of the temperature of mazouts under test from 40° to 70°C., their viscosity varied within wide limits, *viz.*, approximately from 4° to 22° Engler, *i.e.*, up to five or six times the original figure, while the surface tension within the same temperature limits varied from 0·00295 to 0·0027, *i.e.*, up to 9 per cent. only. Inasmuch as the perfection of atomisation, as already mentioned, depends exclusively on surface tension, it was to be expected, *a priori*, that the perfection of mazout atomisation would not vary with a respective rise of temperature, notwithstanding the considerable change of viscosity. We have experimentally proved that, in case of vast variations of viscosity of different mazouts, *viz.*, approximately from 3° to 23° Engler, the steam consumption in atomisers per 1 Kg. of atomised mazout, remains practically constant, provided the perfection of atomisation remains uniform.

Thus, the generally existing view to the effect that the most suitable viscosity range lies between 7° and 9° Engler for steam jet atomisers and between 3°–5° Engler for mechanical ones, has in no way been supported by our experiments, being moreover devoid of any theoretical basis.

For steam jet atomisers, the steam consumption on atomisation has proved independent of grade of mazout used in regard to its paraffin contents. It chiefly hinges on the design of the atomiser as well as on the burner load, being increased with a corresponding decrease of this load. From among the burners, the testing of which has given very good results as regards the economy of steam consumption, we can note the Babcock & Wilcox steam atomising burner, the consumption on atomisation of which under a normal load, has proved to be about 0·2 Kg. of steam per 1 Kg. of mazout atomised.

A subsequent theoretical study of the process of oil fuel combustion in a boiler furnace involves the necesssity of special attention

being paid to the favourable direction of cracking during the initial stages of the process, which is important in obtaining perfect combustion with minimum air excess.

Inasmuch as, according to the data furnished by Professor Bone and his collaborators, cracking runs with more symmetry in the presence of oxygen and at low temperatures, it is necessary to direct a maximum air supply to the burner, provided this does not prevent the ignition and does not tear off the flame from the burner tip. Indeed, when acting accordingly, we obtain these two important conditions, *viz.*, a considerable amount of free oxygen available and a decrease of temperature in the vicinity of the flame ; both these factors being indispensable in attaining the maximum symmetry in cracking as well as the direct oxidation of resulting products, ideally up to formaldehyde, thus eliminating smoke production. Utterly irrelevant is, therefore, the design of the furnace comprising air admission extending along the length of the flame, since air introduced at points remote from the burner cannot be sufficiently utilised in the furnace, the resulting multi-molecular hydrocarbons subsequently offering great opposition to oxidation.

Accordingly, our furnace designs, based on the above principle, always enabled us to obtain perfect combustion in furnaces of minor volume, the excess of air being always very small and the amount of incomplete combustion products practically negligible. In all experiments with fuel oil the excess of air, as determined behind the boiler, *i.e.*, including all the air entering the boiler setting, was $\alpha_c \cong 1{\cdot}2 - 1{\cdot}25$ (20 to 25 per cent. of excess air) in case of complete combustion, while the rate of heat liberation per furnace volume was 300 thousand cal./m.^{3}h. The coefficient of air excess diminished with the increase of $\frac{Q}{V}$ as usual. During individual experiments, complete combustion occured even at $\alpha_c = 1{\cdot}10$ or $1{\cdot}12$, but such a small excess of air had to be abandoned owing to prohibitive wear and tear of refractories.

A very considerable hindrance in the combustion of oil, expecially when using mechanical burners, is caused by an intense wear and tear of settings at high $\frac{Q}{V}$ values, notwithstanding the air cooling of the brick walls. Therefore, it is advisable to use water cooled walls, as in furnaces for pulverised coal, in order to reduce the temperature of the furnace and have a smaller surface of refractories. Direct

measurements, carried out during our experiments, have given readings up to 1,700–1,800°C. and upwards for zones of maximum temperatures at high rates of combustion.

Experiments with turbulent-flame furnaces of the "well" type for the combustion of oil gave no positive results in improving the efficiency of the process, *i.e.*, the reduction of air excess, the testing of such furnaces revealed only considerable damage done to the refractories and a need for frequent repairs of the latter.

As regards the question of unloading paraffin mazout from railroad tank cars, considerable experience has been acquired. At first, the usual method of introducing bare steam into the tank car was tried for the purpose of heating mazout. The drawbacks of this method consist in the great loss of condensing water, which is an undesirable waste in up-to-date boiler houses, as well as in an excessive content of water which mixes up with the mazout, being heated up by bare steam.

As a matter of fact, special tank cars fitted with heating spirals have proved very convenient for unloading paraffin mazout, yet the railroads of U.S.S.R. being rather short of such facilities, an extended application of this method of warming has been found impracticable, for which reason the Thermo-Technical Institute has developed a method proposed by Professor L. K. Ramzin, which consists in heating mazout in tanks by means of a hot jet of the same substance. To effect this, mazout is driven by means of a pump into a heater, where it is warmed up to the temperature of about 100–120°C., and then under a pressure of not lower than 10–15 atm. it is introduced through a hose into the tank as a powerful jet striking upon the surface of solidified mazout. Owing both to the thermal and mechanical action of the jet, part of the mazout in the tank melts and is sucked back by the pump, so that a part of the mazout is continuously making a complete cycle, travelling between the tank, the pump and heater. As the heating process advances in the tank, part of the mazout is directed to an oil storage tank and the warming goes on until the whole tank car is in this way emptied.

This method, thoroughly tested during a whole year of operation, affords approximately the same duration of overflow as the other two previously mentioned, but it eliminates the disadvantage of the latter, *viz.*, the loss of condensing water and the mixing of water and mazout, both involved in the first method; also the necessity of refitting the available tank-car with spiral heaters.

Lastly, on driving mazout through pipe-lines between an oil

storage tank and the boiler house, as well as within the latter, we have succeeded in altogether dispensing with steam tubes often made use of within pipe-lines. This has been arrived at by imparting the requisite gradients to the pipe-lines and fitting the latter, wherever necessary, with air cocks which allow, in case of any section of the line being shut off, to immediately evacuate it from oil, thereby preventing the solidification of mazout in the cooling pipe-lines. Occasional blocks of mazout which, seldom as they did, formed in different portions of the pipe-line, were easily removed by joining steam pipes to the mazout carrying pipe-line. The introduction of steam into the pipe-line always afforded a way of clearing blocks of solidified mazout.

At any rate, the use of paraffin mazout, with pour point of 30°C. and upwards, practised by the Experimental Station of the Thermo-Technical Institute for more than a year, has involved no trouble or delay due to blocks in the pipe-lines.

Therefore, the problem of the utilisation of paraffin mazout has been solved in every detail as regards both unloading the tank cars and pumping mazout, as well as its efficient combustion.

In regard to combustion efficiency the paraffin mazouts have proved absolutely equivalent to those free from paraffin, demanding no special atomisers or furnace design ; the extra costs involved in the use of paraffin mazout are confined only to the heating of mazout in tanks and other parts of the plant.

According to the numerous experiments of the Thermo-Technical Institute, the above total extra cost for paraffin mazout, as compared with that free from paraffin, amounts to as much as 2·2 per cent. on the average. Thus, the experiments of the Thermo-Technical Institute have proved the following : the combustion efficiency of paraffin mazout equals that of paraffinless mazout; no special designs of burners of furnaces for combustion are required ; all troubles associated with unloading and hauling of paraffin mazout may be overcome ; the practical possibility and advantage of the operation of a boiler house using this mazout has been confirmed, not only by laboratory experiments of the Institute, but also by long-continued exploitation at its own experimental station. This opens a vast field to the utilisation of paraffin mazout in any season and in any region of the U.S.S.R., eliminating the strict distribution of particular grades of mazout among regions and seasons, as has been the case heretofore.

ZUSAMMENFASSUNG

In Anbetracht des Verbrauchs bedeutender Mengen minderwertiger Brennstoffe in der U.S.S.R. hat das Studium ihrer Verbrennung bedeutende Fortschritte gemacht und bereits zu einer Reihe wirtschaftlich rentabler Bauarten geführt.

Die Aufgabe der Holzverbrennung, sogar bei recht bedeutendem Feuchtigkeitsgehalt desselben, ist gegenwärtig für kleinere Anlagen durch Anwendung einer modifizierten Bauart der Planroste und Schachtfeuerungen durchaus gelöst. Bei grösseren Anlagen kommt ein neues Verfahren mit künstlich in kleine Stücke zerschlagenem Holz auf Wanderrosten zur Anwendung.

Dieses neue Verbrennungsverfahren von Holz in kleinen Stücken löst in jeder Hinsicht und ohne Erhöhung der Brennstoffkosten die Aufgabe der Verwendung von Holz in den grössten Anlagen, und gestattet, sowohl den Transport als auch die Verbrennung des Holzes bei grösster Wirtschaftlichkeit des gesamten Prozesses zu mechanisieren.

Die Anwendung von Wanderrosten bei feinen, feuchten und nichtbackenden Brennstoffen, wie z.B. bei Braunkohle des Moskauer und Tscheljabinsker Bezirkes und kleinen Anthrazit-Sorten, ist als eine durchaus wirtschaftliche Lösung der Aufgabe der rationellen Verbrennung dieser Brennstoffe anzusehen.

Zur rationellen Verbrennung feuchter und verunreinigter Braunkohle ist die Anwendung heissen Unterwindes bis 200°C von grosser Bedeutung. Wichtig ist auch eine richtige Mauerung der Wanderroste mit langen hinteren Gewölben und guter Vermischung der Abgase.

Zur wirtschaftlichen Verbrennung minderwertiger, feiner, nichtbackender Brennstoffe muss man Wanderroste verwenden, die ein Hindurchfallen des Brennstoffes durch die Rostspalten auf ein Minimum beschränken, und die einen Zonenunterwind mit untereinander abgedichteten Sektionen besitzen.

Am wesentlichsten zur Erreichung einer hohen Wirtschaftlichkeit der Feuerung ist die richtige Wahl der Wärmebeanspruchung des Rostes, die normal für die Mehrzahl der besprochenen Brennstoffe um 900 000 Cal/m^2St herum schwankt, wie auch die richtige Wahl der Wärmebelastung des Feuerraums, die zwischen 250 000–350 000 Cal/m^3St schwanken sollte.

Das Wärmetechnische Institut in Moskau hat die Aufgabe der Verbrennung paraffinhaltigen Masuts sowohl hinsichtlich seiner Ausladung aus den Eisenbahnzisternen und seiner Beförderung durch Rohrleitungen als auch seiner wirtschaftlichen Verbrennung als Kesselfeuerung allseitig gelöst, wobei gleichzeitig eine Reihe von Fragen hinsichtlich der Eigenschaften verschiedener Masutarten, wie auch die Prozesse ihrer Zerstäubung und Verbrennung erleuchtet worden sind. Dadurch wurde es jetzt möglich, paraffinhaltige Masute unabhängig von der Jahreszeit in ganz Russland (in der ganzen Union) zu verwenden.

In dem Berichte sind die mittleren Ergebnisse zahlreicher im Wärmetechnischen Institut vorgenommener Untersuchungen in Zahlenwerten angeführt.

CHARACTERISTICS AND CLASSIFICATION OF FUELS IN U.S.S.R.

STATE THERMO-TECHNICAL RESEARCH INSTITUTE, MOSCOW

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*Paper No. A*12

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AN EFFICIENT CLASSIFICATION OF FUELS

ZUSAMMENFASSUNG

FUEL STUDY IN THE U.S.S.R.

Prior to the Great War little knowledge regarding the characteristics of Russian fuels was available, but as a result of the fuel crisis that arose during the war a special Government Fuel Board was set up and much interest in fuel was generally aroused. This gave the first impulse to a more complete study of Russian fuels and to a more systematic survey of their qualities; but it is only since the Revolution and the beginning of State planning and standardisation that our problem was attacked on a really sound basis. Owing to the nationalisation of industry and concentration of all records in government offices, specialists were afforded full opportunities for obtaining systematic mass figures. At the same time the opening of a number of scientific research institutes after the Revolution greatly fostered a purely scientific investigation of Russian fuels, conducted in a number of special laboratories.

The present paper is the result of fourteen years' study of Russian fuels by the author, and later under his direction by the Thermo-

Technical Institute. From its very establishment the Thermo-Technical Institute has been continuously carrying on systematic work on the study of Russian fuels. The three following lines of approach by way of collecting materials are being made use of for the purpose: (1) The results of mass analyses at official acceptances of fuel by railways and State industrial enterprises, at mines and oil-fields. The collection of such analyses is greatly facilitated by the fact that all results of fuel acceptances by railways are concentrated in the People's Commissariat of Transport, while the results of Donetz fuel analyses for industrial consumers—and recently also those for oil—are all centred in the Institute, as the latter, in the capacity of arbitrator, is entrusted with the selection of samples for the greater part of the Russian industry. The mass acceptance analyses usually show the contents of moisture, ash, sulphur, volatile matter and calorific value, and sometimes also the hydrogen, required for calculating net calorific value. In this way we have fully reliable material for judging of the purity of average market fuels, and of the calorific value of their combustible matter. In the following summary the elaborated results of more than 16,000 analyses of this type have been made use of. (2) The results of analyses carried out by the Chemical Laboratory of the Thermo-Technical Institute proper on behalf of industry, and also at numerous furnace and boiler tests at the Boiler Laboratory of the Institute and at industrial plants. A considerable number of these investigations give also complete analyses of fuels, and often figures as to fusibility of ash are to be found therein. Thus the Institute's analyses corroborate the results of group (1), offering more complete information as to the combustible matter of fuels.

Apart from its own analyses, the Thermo-Technical Institute also makes use of all other printed materials, as well as of the researches of other investigators and Russian research institutes. Here should be mentioned the works of the Geological Committee, the long and systematic researches of Prof. V. S. Krim on the Donetz Basin coals, conducted in the Central Chemical Laboratory of the Donetz Coal Trust, the researches of a worker on the staff of the Thermo-Technical Institute, Eng. A. P. Shahno, on the coals of Kuznetzk Basin, those of Prof. N. M. Kartashov on the coals of the Kusnetzk, Minusinsk and Tcheremhovsk Basins, the researches of the Central Chemical Laboratories of Azneft and Grozneft and also those of Prof. A. N. Sakhanov and a worker on the staff of the Thermo-Technical Institute, B. G. Tichinin, on fuel oil. Further, the works of Prof. N. P. Tchijevski in the Moscow Mining Academy,

the investigations of Prof. J. S. Stadnikov in the Chemical Institute in the name of Karpov, the works of the State Central Peat Research Institute, the Transport Board of Donetz Fuel Acceptance for the People's Commissariat of Transport, and many other laboratories and institutions. The results of these detailed and special investigations have given about 1,000 separate ultimate analyses.

(3) The results of a purely scientific investigation of Russian fuels as carried on in the Thermo-Technical Institute and in the above institutions on the distillation of coals, on the action of solvents upon coals, their microscopic structure, extensive results of investigation of the inorganic matter of fuels, etc.

As a result of the foregoing we are at the present moment able (*a*) to obtain reliable data which may be considered as true average technical analyses of fuels at present consumed in the U.S.S.R.; (*b*) to carry on a really systematic and exhaustive study of the properties of Russian fuels based on scientific research work. The systematisation of all accumulated mass material is, as already mentioned, continuously carried on by the Thermo-Technical Institute, by whose endeavours more than 20,000 analyses have been collected during several years (including 4,000 technical analyses made by the Chemical Laboratory of the Institute). The work not only covers separate coalfields but also individual mines, and sometimes where conditions permit is even extended to coal-seams, so that the Thermo-Technical Institute will soon be able to issue the first Russian catalogue of fuels.

STANDARDISATION OF FUEL QUALITY

This had its beginning in pre-war Russia, as the first specifications for the supply of Donetz fuels to railways were introduced as early as in 1909. These specifications were based on a classification of coals as to their caking power and content of volatile matter. The quality of coal was rated only after the contents of ash and sulphur. Later on, specifications were more than once reconsidered and were simultaneously given greater precision and more careful elaboration.

At present, specifications for coal acceptance are required in all the principal regions of the U.S.S.R. Similar specifications exist also for the acceptance of fuel oil. This year, owing to the accumulation of the above-mentioned mass of material, it was once

again found possible to revert to the problem of fuel classification and to give greater precision to the specifications.

The following public bodies take part in the elaboration of technical standards: the Special Standard Commission of the Supreme Council of People's Economy, the fuel industry taken as a whole, the Bureau of All Union Thermo-Technical Conferences, and experts generally represented by scientific research institutes, scientific and technical councils and individual specialists. The schemes of classification and standards thus worked out are then passed to the State Planning Commission of the U.S.S.R., and after the latter has pronounced itself they are ultimately confirmed by the supreme legislative authorities of the Republic. The fundamentals of the 1925 standards, which are still in force, may be reduced to the following.

Fuel Oil

Fuel oil or mazout is sub-divided into four categories, differing only in regard to pour point. The pour point of the first class "A" should not be above −10°C., while a range of solidifying from +24°C. to +35°C. is admitted for the last class. All other characteristics are equally standardised for all four classes, *viz.*, the lowest flash point should not be lower than 60°C. (50°C. for Grozni), maximum contents of mineral admixtures 1 per cent., alkali 0·1 per cent. and moisture 0 per cent., while the maximum viscosity should not exceed 7° Engler.

The above figures (with no consideration as to moisture) are given to the consumer as limits so that he may reject such fuels as would not be up to standard quality. At the same time a determinate allowance off oil prices is made for surplus mineral admixtures (0·5 to 1 per cent.), and also for all the water content.

Coal

Coals are classified only for the Donetz Basin, which is noted for the variety of its coals. As to other coalfields, the character of coal is already defined by the very name of the particular coalfield, on account of the similarity of the main characteristics. Two main characteristic features underlie the classification of Donetz Basin coals: (1) characteristics of coke determining the caking power of coal, (2) contents of volatile matter in coal, as may be seen from the following table.

TABLE I.

NN	Kind of coal	Mark	Content of volatile matter in dry ashless coal V^e per cent.	Character of coke
1	Dry long flame coal	Д	More than 44	Non-caking, pulverulent or slightly fritted.
2	Gas coal	Г	36 to 47	Caked, melted, sometimes porous (swollen).
3	Steam fat coal (Bituminous coal)	П.Ж.	25 to 36	Caked, melted, compact or moderately compact.
4	Coking coal	К	20 to 36	Caked, melted, compact or moderately compact.
5	Steam caking coal	П.С.	Less than 20	Caked or melted, from compact to moderately compact.
6	Lean coal	Т.	Less than 20	Non-caking, pulverulent or slightly fritted.

Such a primitive but convenient classification was adopted on account of the inefficiency of such schemes as Grüner's, and other similar classifications for Donetz Basin coals. It should here be pointed out that Grüner's classification is just as impracticable for the coals of the Kuznetzk Basin.

Apart from the above fundamental classes of Donetz fuel, the specifications embrace three special grades, *viz.*, smith's washed coal, dry long-flame screenings, and navy coal.

Non-caking coals and anthracites are sub-divided into grades depending on the size of lumps. The following grades of Donetz anthracites are recognised for home consumption.

TABLE II.

Description	Mark	Size of lumps in inches
Lumps	АП	More than 5
Large nuts	АК	5 to 1
Small nuts	АМ	1 to $\frac{1}{2}$
Rice N 1	АС	$\frac{1}{2}$ to $\frac{1}{4}$
Rice N 2	$АС_2$	$\frac{1}{4}$ to $\frac{1}{8}$
Culm	АШ	$\frac{1}{4}$ to 0
Run of mine (without lump)	А.Р.Ш	5 to 0

Furthermore, the following special grades of Donetz anthracite have been selected: foundry and gas-producer anthracites.

The set of export marks of Donetz anthracite is as given in Table III.

TABLE III.

Description	Russian mark	Export mark	Size in English inches	Corresponding English mark
Large	АП	A5	5 and more	Large
Lumps	АК	A4	2 to 3	Cobbles
Large nuts ...	АКС	A3	$3\frac{1}{2}$ to 5	,,
Nuts	АС	A2	2 to $3\frac{1}{2}$	,,
Gas producer ...	АГ	A1	1 to 2	French nuts, Paris nuts, stove nuts
Small nuts ...	АМ	AC	$\frac{1}{2}$ to 1	Beans
Rice	АС	AC	$\frac{1}{4}$ to $\frac{5}{8}$	Peas
Small nuts, rice and culm ...	АМСШ	r.c.	0 to 1	Rubbly culm
Culm	АШ	AD	0 to $\frac{1}{4}$	Duff

A similar sizing based on the dimension of lumps is used in the case of Sub-Moscow Basin brown coals, as in Table IV.

TABLE IV.

Description	Mark	Size of lumps in inches
Lumps	К	Not less than 2
Nuts	О	$\frac{3}{4}$ to 2
Peas	С	$\frac{3}{4}$ to $\frac{1}{4}$
Fines	М	$\frac{1}{4}$ to 0
Run of mine (without lump)	РМ	2 to 0

For other non-caking or open-burning coals, namely, the Kizel, Tchelabinsk, Southern Kuznetzk, Tcheremhovsk and Donetz long-flame screenings, the minimum size of lump is standardised. For the latter types of coal and also for Donetz anthracites there is a fixed amount of culm, above which a reduction off the sale price is allowed. Donetz coals are also tested for mechanical strength with the object of minimising losses arising during transportation, and incomplete combustion, when flue dust and siftings are produced in furnaces.

The specifications for coals supply a limit for the amount of moisture, which being exceeded calls for a discount off the sale price. Prohibitive contents of sulphur and ash are also provided. The specifications are based on the calorific value of absolutely dry coal, determined in a bomb calorimeter. The normal limits of calorific value are determined for every grade and coalfield, the stock price being raised when these limits are exceeded, and, *vice*

versa, an allowance is made when these normal limits are not reached. Finally, prohibitive limits are also given for the calorific value of absolutely dry coal. As already mentioned, the existing specifications were introduced only temporarily, and they are being re-examined and revised.

MAIN CHARACTERISTICS OF RUSSIAN FUELS

From the standpoint of combustion the basic characteristics of fuel are as follows:—

W^h hygroscopic moisture of fuel, which is important from the view point of fuel classification, and as concerns drying preliminary to grinding.

W^f moisture of fuel as fired.

A^d ash content of absolutely dry fuel.

It is obvious that ash content should be estimated only for absolutely dry fuel, so as to eliminate the influence of variable moisture, which, with many fuels, may fluctuate within a very wide range, thereby causing instability of ash content in fuel as fired.

Now, since all technical analyses give only apparent ash content, *viz.*, that directly obtained in laboratory by means of burning in a crucible, we everywhere refer to this particular magnitude only, *i.e.*, laboratory ash content. When scientifically determining the true ash content, it is essential to introduce the value R, applying a correction for changes in the weight of ash due to presence of pyrite, sulphur, carbonates, hydrates, etc. Further, the ultimate analysis of fuel would be most efficiently reckoned from the organic matter, *i.e.*, from fuel deprived of moisture, ash, and sulphur. Owing, however, to the fact that most technical analyses make no distinction between combustible and non-combustible sulphur, it appears more practical to give the ultimate analysis with regard to combustible matter, *i.e.*, on the dry and ashless fuel. In this instance, again, it is not the true combustible matter that is understood, but only the apparent one, distorted by the arbitrary nature and inexactitude of laboratory ash determination. For obtaining the true figure of combustible matter we should introduce the correcting value "R" for ash, and accordingly also for fuel oxygen, which is usually obtained from the difference. The further symbols in the elementary composition of combustible matter should be read as follows:—

C^c percentage of carbon.

H^c ,, hydrogen.

N^c ,, nitrogen.

O^c percentage of oxygen; owing to no correction for ash the magnitude $O^c - R^c$ (instead of O^c) is usually obtained; here R is the change (positive or negative) in ash weight when re-figuring to combustible matter.

S^c combustible sulphur contents.

V^c volatile combustible matter.

Q_g^c gross calorific valve of combustible matter.

Q_n^c net ,, ,, ,, ,, $= Q_g^c - 5{\cdot}85\ (9H^c)$.

Q_g^f gross ,, ,, fuel as fired.

Q_n^f net ,, ,, ,, ,, $= Q_g^f - 5{\cdot}85\ (9H^f + W^f)$.

Since the characteristics of combustible matter are known, it is, of course, easy to re-calculate them for any given amounts of moisture and ash.

Caking power is one of the most essential characteristics of coal. This controls losses due to combustible falling through the grate and being carried away in flue dust. Readiness towards spontaneous combustion and weathering and also the softening temperature of ash are, likewise, among the fundamental furnace characteristics of fuels.

As a reliable objective characteristic of caking power from the standpoint of fuel resistance to outflow of dust during combustion is as yet lacking, caking power in Table V. is described *qualitatively*, the corresponding classes being taken from Grüner's classification. Thus, I stands for the caking power of a given coal to correspond with dry long-flame coals; IV to correspond with caking coals, etc. Zero shows complete deficiency of caking power, which is typical of anthracites, brown coals, etc. The fusibility of ash is everywhere characterised by the softening temperature in semi-reducing atmosphere, which always secures a minimum value of this magnitude. For judging fuel properties with regard to combustion the above characteristics may practically be considered exhaustive. A summary is to be found in Table V. embracing all important kinds of Russian fuels of industrial value at the present time.

We must say that the table is far from characterising all existing Russian fuel, but deals with those only that are being worked at present, and the output of which tends to assume a more or less considerable figure. The ballast figures contained in the table, *viz.*, moisture and ash contents, are typical for industrial fuels marketed. They were determined by the many thousands of mass analyses referred to above. For most fuels the ash content of coals in seams should of course be plotted much lower. Further, the very

TABLE V. MAIN CHARACTERISTICS OF RUSSIAN FUELS FOR 1927.

NN	Kind of fuel	Region	Origin and grade of fuel	Mark	Size of lump in mm.	Apparent combustible matter V^e	C^e	H^e	N^e	O^e-R^e	S^e_o	Q^e_g	Q^e_n	Dry fuel A^d	Fuel "as fired" W^f	Q^f_g	Q^f_n	Hygroscopic moisture W^A	Softening temperature of ash °C.	Characteristics of coke	Weathering	Spontaneous combustion
1	Firewood	Firewood (coniferous)		·		84	51·0	6·2	0·6	42·2	0	4880	4555	1·0	30	3380	2980	8	—	Separate compact lumps	Nil	Nil
2		Firewood (foliate)				86	50·0	6·15	0·6	43·25	0	4740	4420	1·0	30	3285	2885	8	—			
3		Firewood (mixed)				85	50·5	6·2	0·6	42·7	0	4840	4515	1·0	30	3355	2950	8	—			
4	Average peat Central-Industrial Region					70	58·8	6·0	2·0	33·0	0·2	5650	5335	9·0	30	3600	3220	11	1160			
5	Brown coal	Sub-Moscow	Lump	K	<50	45	70·7	5·3	1·4	18·8	3·8	6830	6550	20·0	32	3715	3380	7	1250	0	Very strong	Very easy
6			Nut	O	50–20	45	68·2	4·8	1·4	18·6	7·0	6540	6290	27·5	31	3270	2965	7	1250	0		
7			Fines and pea	MC	20–0	45	68·4	4·9	1·4	19·8	5·5	6540	6280	31·0	32	3070	2760	7	1250	0		
8			Run of mine (without lump)	PM	50–0	45	68·3	4·8	1·4	19·0	6·5	6540	6290	31·0	33	3025	2715	7	1250	0		
9		Ural	Tcheliabinsk			44	72·9	4·9	2·0	19·0	1·2	6920	6660	15	17	4880	4600	10	1150	0	Slight	Nil
10			Bogoslovsk			42	67·5	4·2	1·5	26·2	0·6	6020	5800	14·2	26	3820	3530	17	1110	0	Strong	Nil
11		Eastern Siberia	Tchernovsk			47		5·3			0·7	7000*	6720	8·5	33	4290	3930	17		0		
12			Kivda			40		4·3			0·3	7000	6775	12·5	25	4595	4300	10·5		0		
13			Zyboonny			48		5·7			0·8	7190	6890	12	26·5	4650	4300	11		0		
14			Tavrichansk			49		5·6			0·3	7500*	7205	16·5	13	5450	5160	9·5		0		
15	Coal	Donetz Basin	Dry long-flame coal	Д		45	77·0	5·4	1·8	10·8	5·0	7730	7445	12	11	5915	5635	5	1150	1	Strong	
16			Gas coal	Г		39·5	81·0	5·5	1·6	7·9	4·0	8080	7790	12·5	5	6715	6445	3	1110	II	Considerable	
17			Steam fat coal	ПЖ		30·5	85·5	5·2	1·6	4·7	3·0	8440	8165	13	4	7050	6795	1·3	1160	III-IV	Slight	
18			Coking coal	К		23	87·0	4·9	1·6	3·5	3·0	8540	8280	13·5	3	7165	6930	1·0	—	IV	Slight	
19			Steam caking coal	ПС		16·5	89·0	4·5	1·6	2·4	2·5	8580	8345	11	3	7405	7185	0·7	1101	IV	Slight	
20			Lean coal	Т		12·5	91·0	4·1	1·5	2·2	1·2	8560	8345	7·5	3·5	7640	7430	0·5	1140	V	Nil	
21	Anthracites	Basin	Lumps	АП	<125	4	94·5	1·85	0·7	1·35	1·6	8160	8065	4·5	5	7405	7285	1	1180	0		
22			Large nuts	АК	125–25	4	94·5	1·85	0·7	1·35	1·6	8160	8065	6	5	7285	7170	1	1180	0		
23			Small nuts	АМ	25–13	4	94·3	1·85	0·7	1·35	1·3	8140	8045	10·5	5	6920	6810	1	1180	0	Nil	Nil
24			Rice	АС	13–6	4	94·3	1·85	0·7	1·35	1·8	8140	8045	14·5	6	6540	6430	1	1180	0		
25			Culm	АШ	6–0	5·5	93·0	2·0	0·8	2·7	1·5	8020	7915	18	8·5	6015	5890	1	1180	0		
26			Run of mine (without lump)	АРШ	125–0	4	94·0	1·9	0·7	1·9	1·5	8140	8040	13·5	6	6620	6500	1	1180	0		
27		Ural	Yegorshin			9	92·5	3·5	0·6*	2·8	0·6	8450	8625	18*	5*	6585	6410	1	>1400			
28			Poltava			3	96·0	1·1	0·5*	2·0	0·4	8050	8000	19	8	6005	5915	1*				
29			Bredinsk			3·5	93·4	1·5	0·7	3·6	0·8	7950*	7870	15	8*	6215	6110	1*				
30		Ural	Kizel			41	78·5	5·2	0·7	8·6	7·0	8000	7725	23	5	5850	5620	1	1300	I-III	Slight	Nil
31			Lunievski			42	76·6	5·5	0·9	9·2	7·8	7970	7680	33	5	5075	4860	1		I-III		
32		Caucasus	Tkvibooli			42	78·8	5·0	1·6	13·3	1·3	7660	7395	16·5	9	5820	5565	5	>1400	I-II	Considerable	
33		Fergana	Soolewkta			36	76·0	4·0	1·0	17·0	2·0	6950	6740	16·5	18	4760	4510	11		I	Slight	Strong
34			Kizil Kiya			36	76·0	4·0	1·0	17·0	2·0	6950	6740	9·5	26	4655	4360	11		I		
35		Kuzuetzk Basin	Anjera Sudjensk			16·5	90·2	4·3	1·5*	3·3	0·7	8600	8375	9·5	5	7395	7170	1	1300*	IV-V		
36			Lenin (Koltchugin)			41	82·0	5·6	2·4	9·3	0·7	8105	7855	9·5	9	6710	6415	2·5*	1120	II-III		
37			Kemerovo			28	86·2	4·9	1·8*	6·3	0·8	8380	8120	11·5	8·5	6785	6525	2·5	1120	IV-III		
38			Prokopjevo and Kiseliovo			21	87·1	4·0	2·1	6·3	0·5	8100	7890	12	7	6630	6415	3	>1300	I-II		
39		Minusinsk	Tchernogorski			41		5·3			0·5	7850	7570	6	11·5	6530	6230	7·5		II	Nil	
40		Irkutsk	Tcheremhovski			47	78·0	5·8	1·5	13·6	1·1	7750	7445	14·5	9·5	5995	5705	5	1160	II-I		
41		Soochan	Fat Coals			25		5·1			0·5	8600	8330	15	4	7020	6775	1·2		II-III		
42	Oil shales	Veimarn		$(CO_2)^e$	=20·6	80	75·0	9·0	0·3	13·7	2·0	6440[2] / 8100	6065[3] / 7625	45+11·3[a]	25[c]	2655	2355	2·5	1160	0		
43		Kashpoor		$(CO_2)^e$	=21·9*	80	69·8	9·0	2·0*	14·4	4·8	6760 / —	6555 / —	59+9[a]	18[c]	2240	2005		1080	0	Nil	Nil
44		Undor		$(CO_2)^e$	=17·2	70	66·5	8·0	2·0*	19·0	4·5*	5850 / 7100	5500 / 6680	61+6·7[a]	25[c]	1710	1470	3*	1040*	0		
45	Coke	Donetz metallurgical				4*	95·6	0·7	1·3	0·5	1·9	7980	7945	13	7·5	6420	6350	0·8		0	Nil	Nil
46		,, foundry				4*	96·4	0·7	1·4	0·5	1·0	8000	7965	11·5	7	6585	6510	0·8		0		
47	Charcoal: Dump charcoal					11*	91*	2*	7*		0*	7800*	7695*	2·0*	9	6955	6810				Nil	Nil
48	Oven charcoal						80*	4*	16*		0*	7300*	7090*	2·0	10	6440	6195					
49	Mazout (γ_{15}=0·900—0·905)					—	86·65	12·7	0·5		0·15	10760	10090	0·1	2*	10535	9870	—	—	—	Nil	Nil

NOTES

1. Figures with the asterisk mark (*) are merely approximate, being taken on the ground of a small number of analyses or according to estimate.

2. Softening temperature indicates mean of softening point in semi-reducing atmosphere and is only a rough proximate average of ash fusibility varying in both directions within a wide range with regard to individual mines and seams.

3. Apparent laboratory ash content A^d is given in all cases, for which reason combustible matter has not a true but only a conventional value, and contains not the true amount of oxygen, but C^e-R^e, where R^e is an algebraic increase of ash weight (positive or negative) when heated in crucible

4. Coke, as regards external characteristics, is classed after Grüner.

(a) The first item stands for apparent laboratory ash, while the second represents all carbonic acid gas emitted in the disintegration of carbonates.

(b) Upper figures are given with estimate for apparent combustible matter obtained after subtraction of moisture and laboratory ash only, i.e., combustible matter including also carbonic acid gas resulting from the disintegration of carbonates; bottom figures refer to combustible matter with correction for carbonic acid obtained after subtraction of laboratory ash moisture and the carbonic acid of carbonates, but without correction for the action of hydrates, pyrite, sulphur, etc.

(c) Natural moisture in seam is indicated; market moisture amounts to about 15 per cent. for all the three kinds of oil shales.

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composition of combustible matter also represents a certain average for the fuels of a given coalfield or class; of course, in reality, more or less considerable deviations are always to be found from these averages.

We have naturally introduced the necessary sub-divisions in the case of all fields, different portions of which produce fuels of varying description. But there again we had in view only the characteristics of existing market fuels. Some further explanatory comments on the table are to be found below.

Wood Fuel

Since this particular kind of fuel is of especial importance under Russian conditions, we have, of late, made a series of complete analyses of wood fuel, so that the composition of the latter is characterised by more than 100 complete analyses, and may, therefore, be said to be altogether reliable. For Russian genera of timber the calorific value of combustible matter taken from coniferous trees is about 150 cal./Kg., or 3 per cent. higher than that taken from foliate trees.

Peat

The table gives the average quality of peat from the central industrial region of the U.S.S.R.; since it is this particular area that supplies the predominant amount of peat generally produced. Ukrainian and, partly, also Ural peats give a much higher ash content, A^d=15 to 20 per cent. Similarly, for Russian peats the percentage of carbon in combustible matter (ash and moisture-free fuel) generally varies within the range of C^c= 52 to 64 per cent.; depending on the age of the given peat. The predominant number of peats produced in the central industrial region have, however, a composition closely approaching that indicated in our table. The age of peat also determines the contents of volatile matter, for Russian peats it may be expressed by the following empirical formula: V^c=157—14·7C^c per cent.

Brown Coals

Under Russian conditions brown coals are of quite secondary importance. Of all fields worked at present, only the brown coals of the Sub-Moscow, Bogoslowsk and Tcheliabinsk regions have any industrial value. Some Siberian mines are also exploited at present, namely, those of Tchernovsk, Kivda, Zyboonny and Tavrichansk. The rather numerous remaining seams of brown

coals in the U.S.S.R. have either not been worked at all, or have been abandoned, or still have an altogether insignificant output for local consumption only. All such deposits have not been incorporated in the table.

Coals

Coals are adequately represented by all existing coalfields and types assuming any industrial importance at the present time. The leading place is taken by the Donetz Basin, covering about 77 per cent. of the output, next comes the Kuznetzk Basin with about 8 per cent., and at last, the Kizelovsk and Sub-Moscow Basins with 3 per cent. each, so that the said four regions give as much as 91 per cent. of the total coal output of the U.S.S.R.

As may be seen from the table, only the Sub-Moscow brown coals and Kizel-Lunievsk coals possess a high ash content, while ash contents average 11 to 12 per cent. for the remaining coals and brown coals.

Anthracites are at present nearly exclusively obtained from the Donetz Basin. An insignificant production of anthracite also takes place in the Yegorshin and Poltavo-Bredinsk regions in the Urals.

All evidence derived from chemical analyses and contained in the table refers solely to grades marketed in the interior of the country. All export grades are considerably higher.

Oil Shales

These are represented in Table V. by three fields: the Veimarn field near Leningrad, and then the Undorsk and Kashpoorsk fields in the region of Sizran and Oolianovsk (Middle Volga). An inconsiderable production of oil shale now takes place in the Veimarn district only.

Since oil shales contain a large amount of carbonates, and their ash weight is, therefore, considerably distorted, their ash content in the table is given as the sum of two magnitudes, of which the first stands for apparently laboratory ash, obtained as residue after burning in a crucible, and the second stands for carbonic acid resulting from the disintegration of carbonates, so that the sum shows the true ash contents (without correction for hydrates, pyrites, etc.). Accordingly, the calorific values of combustible matter are shown both for apparent combustible (obtained through subtraction of moisture and laboratory ash) and for true combustible matter obtained after subtraction of moisture and true ash.

The ultimate analysis of oil shales is given with estimated true combustible matter. Content of volatile matter is shown together with carbonic acid, produced from carbonates, and for apparent

combustible matter. As most analyses lack the necessary data for re-figuring to true combustible matter, an analytic sub-division of carbonates is extremely difficult.

Oil shales assume hardly any industrial importance at present.

Bogheads and Sapropelites

These are now hardly worked at all. A small number of bogheads is only produced in conjunction with the brown coals of the Sub-Moscow Basin. A large number of bogheads and sapropelites, rich in volatile matter and tars, is to be found in numerous but small Siberian fields, of which the Matagan, Olonkov, Khaharei, Barhat, Kasianovsk and Priangarsk should be mentioned.

Mazouts

In connection with the work on the combustion of mazouts with high paraffin content the Thermo-Technical Institute has in recent years carried out a number (more than ninety) of complete analyses of Russian mazouts, with pour points up to 40°C. Our researches proved the elementary composition of all four grades of Russian mazout to remain constant, in accordance with the composition shown in Table V. as the specific gravities of all four grades fluctuate within a very small range, namely, only 0.900 to 0.906 on the average. The average content of floridine tars was also found to be very close for all four grades, averaging about 11 per cent. The paraffin contents of paraffinless mazout, grade "A," with pour point below −10°C., was about 1·6 per cent., increasing up to 10·5 per cent. for paraffin mazout with average pour point +35°C.

At a temperature of 50°C. the average viscosities of mazouts were likewise found to be very close to one another, fluctuating about 4°Engler, easily solidified paraffin mazouts having at temperatures somewhat above 35°C. even a lower viscosity than paraffinless mazouts (viscosity being ascertained mainly through the availability of tars) and rising to 20 to 30°Engler, and still higher with tarry mazouts. When the specific gravity of mazout increased, the hydrogen contents and calorific value of combustible matter are necessarily reduced.

AN EFFICIENT CLASSIFICATION OF FUELS

The accumulation of analytic material in sufficient quantity now enables us to face the problem of an efficient classification of Russian fuels, mainly from the standpoint of furnace technique. We do not intend here to propound the important and complex problem

of fuel technology, undertaking only to give a brief survey of the general lines along which the elaboration of this problem is being carried on in the Thermo-Technical Institute. We also want to single out some peculiar lines of approach which we have found efficient in the present instance.

Taking into account isomeric phenomena, it is possible to say from the very outset, that only *one* elementary composition cannot by any means underlie a complete classification of fuels. Hence, Seyler's well-known classification, for instance, would not offer a relevant solution of the problem. Let it suffice to refer to a typical instance of a Sapromixite, so called the "Tomit," discovered on the banks of the Tom river in Siberia by A. A. Sniatkov. As disclosed by the investigation of Prof. N. D. Zalesski, the composition of organic matter of this Sapromixite was as follows:—

$C^o = 82{\cdot}7$ per cent.
$H^o = 5$ per cent.
$O^o + N^o = 12{\cdot}3$ per cent.

Thus, as regards its elementary composition this Sapromixite hardly differs at all from common coals; but the distinction becomes very salient if one remembers that with this Sapromixite the percentage of volatile matter is 93 per cent. (organic matter), while coals of same composition have but 25 to 40 per cent. of volatile matter. Judging from available materials it would appear probable that an efficient scientific classification of fuels might be made on the ground of these three basic properties: contents of C^o H^o and V^o. —(the latter symbol standing for volatile matter) in the organic matter of fuel which matter is the sum of $C^o+H^o+O^o+N^o$.

One would be inclined to think that the said three factors fully determine the properties of fuel; for O^o+N^o is determined from C^o and H^o, hence, the elementary composition of the organic matter and, consequently, also its calorific value are thereby ultimately determined, the calorific value being practically always a homologous function of fuel composition, Now, the contents of volatile matter characterises just that particular property of fuel which cannot be accounted for by its elementary composition, because of the above-mentioned isomeric phenomena. At the same time the contents of volatile matter is the most important characteristic both as regards the inherent chemical structure of fuel and the furnace process, because the combustion process and, consequently, also the design of the furnace will evidently in the first place depend on the distribution of *liberated heat* between the fuel bed—*viz.*, the

grate—and the combustion chamber. Knowing the calorific value and the contents of volatile matter we can now judge how much heat is liberated in the fuel bed, and how much in the combustion chamber. We can also judge not only of the quantity but also of the fundamental composition of volatile matter burning in the combustion chamber.

With reference to the data collected, we believe that these three factors also determine the fourth, namely, the caking power of coals. Should this surmise, however, not hold good, it is, nevertheless, certain that caking power should be recognised as one of the fundamental classification features of coals. Apart from the fact that the caking power of fuel determines its use for various technical purposes it appears to be a fundamental property of fuel also from the standpoint of the combustion process.

Numerous comparative testings of various coals and brown coals made in the Boiler Laboratory of the Thermo-Technical Institute have shown that with a high rate of combustion on the grate some of the most considerable losses with non-caking fuels are due to their being carried away by flue gases. This loss sometimes amounts to 20 to 25 per cent. and more of the calorific value of the fuel, and at length determines the whole efficiency of the combustion process. Therefore, when burning fuel on the grate, caking power, considered as the capacity of providing a reliable resistance to the escape of flue dust, is one of the main fuel characteristics, determining the possible combustion rate as well as efficiency in combustion.

Unfortunately, up to date no methods for determining caking power from the standpoint of furnace technique have been devised. As our investigations have proved, Campredon's method also fails to achieve positive results in this connection, for very often, *ceteris paribus*, we obtained much larger losses in flue dust for one fuel, as compared to another, although the former had a much higher index when subjected to the Campredon test.

Having in view to elucidate caking power as the capacity of resisting flue dust escape, the Thermo-Technical Institute is at present undertaking systematic laboratory researches in this direction. A specially designed contrivance has been built for the purpose. It consists of a small laboratory oven capable of collecting all particles carried away in cyclones and dust collectors. We are not going to anticipate the results of this as yet uncompleted work, but we have purposely called attention to it in order to emphasise the importance of caking power from the standpoint

of its practical recognition, and also the necessity of working out laboratory methods of quantitative measurement of this leading fuel characteristic.

From a purely practical industrial point of view we might do with three characteristics only, *viz.*, contents of volatile matter, calorific value of combustible matter, and caking power. In other words, the classification of Prof. Parr (in 1922) would appear altogether sufficient. It should, however, by all means be supplemented by the characteristic of caking power.

It is owing to these considerations emphasising the tremendous importance of caking power that this characteristic was recognised as underlying the classification of Donetz coals.

Concluding my paper, I should like to express a wish regarding a certain unification both as regards methods of laboratory fuel investigation and also commonly employed terminology and symbols. When co-ordinating large numbers of analyses one constantly has to waste a tremendous amount of time deciphering individual analyses for the purpose of ascertaining whether the given values refer to moist or dry coal, whether gross or net calorific value is understood, if general contents, or only combustible sulphur is given, etc., not to speak of laboratory results often needing these or other corrections fully dependent on the analytic methods that are applied in the given instance. The Bureau of Thermo-Technical Conferences in the U.S.S.R. has, to a great extent, already fulfilled this work, thanks to which fact we, in the U.S.S.R., now possess standard methods of laboratory fuel analysis, as well as a single terminology and one system of symbols. This greatly facilitates the co-ordination of numerous analyses, eliminating all misunderstandings and often even those blunders, which sometimes occur in laboratory methods. The ever-developing co-operation of all nations in the solution and elaboration of scientific problems to which the swift scientific and industrial progress of the last few years is certainly due, calls ever more insistently for an international unification of laboratory methods on a world scale, as well as for a common language in the terminology and symbols pertaining to fuel investigation. It seems high time to undertake a similar work also in the domain of furnaces, boilers and power plant test.

I believe that the World Power Conference, which so truly expresses the co-operation and scientific fellowship of different nations, should take the initiative in this important problem, the solution of which would greatly facilitate the exchange of scientific and industrial experience gained in individual countries.

ZUSAMMENFASSUNG

Dank der Verstaatlichung der Brennstoffindustrie und der Möglichkeit, ein umfangreiches analytisches Material in bezug auf die Eigenschaften der verschiedenen Brennstoffe zu erhalten, wie auch dank der Entwicklung der Institute für wissenschaftliche Untersuchungen in der U.S.S.R., hat das Studium der Eigenschaften russischer Brennstoffe während der letzten sechs Jahre bedeutende Fortschritte gemacht. Auf Grund zahlreicher nachgeprüfter Analysen, welche die Gesamtmasse des technischen Brennstoffes genau charakterisieren, haben wir heute die volle Möglichkeit, eine durchaus sichere Charakteristik der russischen Brennstoffe zu geben.

Die Arbeit des Staates auf dem Gebiete der Standardisierung der Industrie, wie auch die Arbeit der wärmetechnischen Konferenzen und wissenschaftlichen Institute der Republik haben bereits zur Schaffung genauer technischer Lieferungsbedingungen und Normen für Brennstoffe geführt und die nötige Klarheit und Präzision in die Beziehungen zwischen Lieferanten und Konsumenten des Brennstoffes gebracht und gleichzeitig die Vertiefung des systematischen Studiums der russischen Brennstoffe gefördert.

Das vom Wärmetechnischen Institut in Moskau systematisch gesammelte umfangreiche analytische Material in Gestalt von vielen tausend Brennstoffanalysen gewährt heute die Möglichkeit, als Resultat der vom Institut vorgenommenen Bearbeitung dieses Materials eine klare Vorstellung von den tatsächlichen derzeitigen Eigenschaften des Brennstoffes nicht nur der einzelnen Bezirke, sondern auch der einzelnen Grubenflöze zu erhalten.

Die angeführte Tabelle bringt eine Zusammenfassung der gegenwärtigen Hauptmerkmale für sämtliche Arten russischer Brennstoffe, denen heute industrielle Bedeutung zukommt. Diese auf Grund von mehr als 20 000 Analysen zusammengestellte Tabelle charakterisiert demnach genügend sicher den heutigen russischen industriellen Brennstoff.

In Anbetracht der dominierenden Bedeutung der Backfähigkeit des Brennstoffes hinsichtlich seiner wirtschaftlichen Ausnutzung in Feuerungen und seiner anderweitigen technischen Verwendung muss die Backfähigkeit sowohl vom wissenschaftlichen als auch vom praktischen Standpunkte aus einer rationellen Brennstoffklassifikation zu Grunde gelegt werden. Das Fehlen objektiver und rationeller Methoden zur Messung des Zusammenbackungsgrades, hauptsächlich vom Standpunkt der Heiztechnik, macht die vom Wärmetechnischen Institut in dieser Richtung bereits begonnene Arbeit unerlässlich. Es werden kurze vorläufige Überlegungen hinsichtlich der Grundprinzipien für die Aufstellung einer rationellen Klassifikation der Brennstoffe gegeben.

Zwecks Erleichterung und Erhöhung der gegenseitigen wissenschaftlichen Mitarbeit der einzelnen Nationen, wovon die gegenwärtig tagende Konferenz ein eklatanter Beweis ist, muss man eine internationale Unifizierung der umfangreichen Laboratoriumsuntersuchungsmethoden bei den verschiedenen Brennstoffen, wie auch eine einheitliche Terminologie und Symbolik anstreben.

FUEL RESEARCH AND FUEL ECONOMY IN ITALY

MINISTERO DELL'ECONOMIA NAZIONALE, AND
ASSOCIAZIONE NAZIONALE PER IL CONTROLLO DELLA COMBUSTIONE

PROF. M. G. LEVI AND PROF. C. PADOVANI

Paper No. A13

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THE ITALIAN SITUATION WITH REGARD TO FUEL—ASCERTAINMENT OF RESOURCES—FUEL STUDIES AND RESEARCH—TRAINING OF FUEL TECHNICIANS—ECONOMY AND CONTROL OF COMBUSTION

The Italian Situation with regard to Fuel

The problems of heat and fuel are, perhaps, the difficult questions which weigh on the economic and also the political situation of Italy.

Italy on the whole possesses few minerals, particularly as regards both liquid and solid fuel. Italian imports of coal reached 14,000,000 tons in 1926, and the total importation of oils amounted to 1,000,000 tons.

These figures, which even surpass any pre-war ones, prove that industry in Italy is developing and growing, but they also show that about $2\frac{1}{2}$ milliard liras have to be found yearly, to provide the necessary blood for our industrial life.

The Italian water-power resources are considerable. It would be imprudent to give, at present, any figures in connection with this natural wealth; rather, it is advisable to wait for the results of the careful investigations now being carried out by the R. Servizio Idrografico of the Ministry of Public Works, on the developed and undeveloped water-power resources of the various Italian regions.

We can, however, state that utilisation of water-power resources is proceeding in this country with great industrial activity, and is being carried out with a very high degree of technical perfection; and that of late years the increasing number of hydro-electric installations was not accompanied by a proportionate increase in the demand and consumption of power.

Italian water-power resources, for the most part in mountainous territory, are generally irregular in supply, requiring costly works when constructed, and must often be supplemented by thermo-electric power plants.

To sum up, if we take into consideration the increase in population and the continual growth of Italian industries, we must not expect the development of the utilisation of hydro-electric energy appreciably to reduce the importation of coal and petroleum in the near future.

Italy possesses several deposits of peat and lignite and insignificant quantities of coal. The total amount of these fuels of home origin, according to present data and forecasts, is from 400 to 500 million tons.

More than two-thirds of this modest total is made up of peat and of very young lignite, for the greater part with high moisture content (40-50 per cent.), and high ash content (15-35 per cent.). These resources are distributed among about fifty deposits, of which many are very small, and the cost of excavation is generally high.

Notwithstanding the abundant superficial indications and the favourable opinion of many geologists, Italian petrol wealth, as so far ascertained, is extremely limited, and such as to allow of an annual production of only about 5,000 tons, *viz.* 0·5 per cent. of the total quantity imported.

There are many springs of natural gases all over Italy, but their usually limited output and their location in almost inaccessible places and far from industrial centres has so far hindered their being worked.

Italy also possesses fairly important fields of shale and bituminous chalk, especially in Sicily and in the Abruzzi.

Although we have not as yet very certain data on the extent and wealth of these fields, it appears that they are important. At present they are only partially worked, and almost exclusively for asphalt for street pavements, or heavy oils. There is no doubt that these minerals are, in addition, capable of yielding light oils and motor fuel by simple distillation or by distillation followed by cracking and hydrogenation.

Although it is not likely that the fuel oils and motor fuel obtainable in this way can in the near future enter into competition with the derivatives of petroleum, these mineral fields undoubtedly constitute a valuable reserve for Italy, and it is essential that they should be carefully examined so that when necessity arises, all the data for their profitable use may be available. Industrial studies and

trials of these shales are in hand, under the supervision of, and with the support of the Government.

These being the conditions in Italy with regard to fuel, it is evident that the work of the Government, of the technicians, and of the manufacturers of this country must above all be a work of research, of study and of education with a view to attaining the following objects:—

(1) Ascertaining the quantity and the quality of the national resources.

(2) Development of study and research in the matter of fuel and thermo-techniques, for the purpose of making the most rational and complete use both of the modest national resources, and of the costly imported fuel, with an eye at the same time to the development of up-to-date processes for the preparation of new fuels.

(3) Instruction of specialist technicians in questions of combustion and fuel.

(4) Education of consumers in economy in the use of fuel, controlling from this point of view the characteristics and the working of industrial thermal plants and of those industries which in any way work or utilise fuel.

Ascertainment of Resources

With regard to ascertaining the quantity and quality of the national resources, the National Government is energetically reviewing and completing all data already to hand, and is also urging, organising, and controlling mining operations of old and new mines.

Among the recent Government enactments in this connection, may be noted the reform of the mining law which lays down that the mineral rights are the property of the State, which controls the researches and the mining activities of the grantee, and also establishes the principle of the repeal of concessions whenever the activity of the grantee should appear not to be in harmony with the demands of the national economy.

For enforcing the mining law for the concessions and the granting of Government subsidies towards private and industrial initiative, the Ministry of National Economy makes use of the judgment of the Consiglio Superiore delle Miniere, constituted of eminent specialists nominated by the Minister himself.

As regards research work on petrol, this was entrusted to a special body controlled by the Government—the Azienda Generale Italiana Petroli—which has undertaken an extensive series of enquiries

based upon the examination of superficial manifestations of a geologic, geophysic and geoseismic nature, and boring in carefully chosen localities.

The exploration of the subsoil and the experimental mining are supplemented by the technical chemical examination of the various products on the part of specialist laboratories, and above all by the Fuel Section attached to the R. Polytechnic of Milan.

Fuel Studies and Research

The poor resources as regards fuel and also the limited development of industries in this country up to a short time ago, have been such that the study of the technique of combustion, up to the last few years, has been insufficiently developed and has, above all, lacked any co-ordination.

The first centre of studies on fuel originated and gradually developed in the High School of Industrial Chemistry, founded in Bologna seven years' ago under the direction of Prof. Mario Giacomo Levi.

The National Government, which had from the beginning morally and materially supported Professor Levi's initiative, instituted in 1926 under its own direction, a section for studying and systematically investigating fuels, with a subsidy of 250,000 liras per annum. This section, which in 1927 with Professor Levi and his principal collaborators was transferred to the R. Polytechnic, Milan, is charged with the chemical-technical study of fuel and combustion; and acts as a consultative body for the Ministry of National Economy in this matter.

The studies so far developed by Professor Levi and his collaborators at Bologna and Milan have aimed principally at:—

(1) The thermal and chemical examination of the principal Italian deposits of peat, lignite and fossil coal, with special regard to their behaviour when distilled at low temperature.

(2) More detailed researches on the distillation of the products of some of the most important deposits, with examination and work on an industrial scale of low temperature tar.

(3) Study of sulphur compounds and of the possibility of desulphurisation of the vast Sardinian and Istrian fields of pitch lignite, which contains as much as 10 per cent. sulphur in the natural fuel.

(4) Studies on hydrogenation by the Bergius method, of Italian lignite, and also of their semi-coke and their tars. Studies of hydrogenation and cracking under pressure of shale oils and heavy Italian petrols.

(5) Examination of about a hundred natural springs of combustible gas in central and northern Italy with tests on extraction of gasoline from gas from the petrol region.[1]

At present, the Fuel Section, which has just finished its new installation at the R. Polytechnic, and which possesses a very modern and complete plant, both for analysis and for laboratory researches, and for demonstrations of an industrial kind, is engaged upon making researches of synthesis from water gas at ordinary pressures and under pressure, further researches connected with hydrogenation in the presence of catalysers, demonstration of the manufacture of gas from Italian fuel, study of bituminous rocks, study of the radio-activity and rare-gases content of natural gases and of the possibility of utilisation of these gases.

Besides the Fuel Section, other laboratories are engaged in the study of fuels in Italy.

The National Council for Research have nominated a special committee for the co-ordination of these studies.

Further, certain industrialists have taken the initiative in making trials of low temperature distillation, and of the synthesis of methyl alcohol.

Training of Fuel Technicians

As regards the instruction of young experts in technical matters connected with fuel and combustibles, the first step was made with the institution of a course of chemical technology of heat and fuel at Royal College of Industrial Chemistry, of Bologna, in the year of its foundation.

In 1927, when Professor Levi was transferred to the Chair of Industrial Chemistry at the Polytechnic of Milan, he applied for and obtained the institution of a similar course to be held by Professor Padovani for the pupils of chemical industrial engineering at the same College.

In the same year, owing to the initiative of the Italian gas industry, which supplied the necessary funds, a six months' course in gas

[1] The researches executed by the Fuel Section during its first years of activity have been collected in a book: "Studies and Researches on Fuel," edited by the National Association of General and Applied Chemistry—Rome—Via 3 Novembre, 154.

The authors regret that the work necessitated by the recent installation at the Polytechnic has prevented them from contributing more recent personal work to the Fuel Conference of London, but have placed at the disposal of the English Technical Committee ten copies of this volume. Other free copies may be obtained for the heads of the Foreign Delegations by applying to R. Polytechnic of Milan (Italy)—Sezione Combustibili.

engineering was instituted, open to those graduates in engineering who intended devoting themselves particularly to the gas industry.

Lastly, during the academic year 1928-1929, the Polytechnic of Milan will open a thermo-technical school, comprising annual courses on chemical technology, and the physical and mechanical technology of heat, together with laboratory and factory practice.

This course will also be reserved for young men who have graduated in engineering, and will give a diploma of specialisation in thermo-technical engineering.

In this manner, a complete centre for the thermal, chemical and mechanical study of the problems inherent in fuel, and for the education of experts specially adapted to the study of thermo-technical problems, will gradually be formed at the Polytechnic of Milan.

Economy and Control of Combustion

The education of the consumers and control as regards the economy of combustion is also a matter of particular care by the National Government. This attention shows itself in the activity of the above-mentioned organisation, and is also shown in the publication of decrees and special provisions dealing with the most urgent problems.

We quote (among other things), by way of example, the government decree for the compulsory recovery of benzol by gas and coke works; that for the compulsory use of fuel of home origin, whenever favourable conditions present themselves; and recently the nomination of a Central Government Commission charged with reviewing and defining contracts relating to the production and consumption of gas for lighting purposes, both as regards the technical requirements of the gas and its price.

But the work of control, in the matter of fuel, is especially entrusted to the National Association for the Control of Combustion, resulting from the fusion and co-ordination of the old associations among the boiler users. To this association is entrusted the supervision of the industrial thermal plants, and the control of their efficiency and regularity.

The association can oblige the users to make renewals and to substitute for old plants, modern ones; it institutes examinations for the selection of the expert staff necessary for the development of its activity, and competitive examinations for solving special problems relating to the economy of fuel, as, recently, a trial on a motor-road of motor-cars fitted with gas-generators. The work of the National Association for the Control of Combustion is closely

related with that of the Fuel Section and of the Thermotechnical School of the Polytechnic for Milan.

Thus, by means of this manifold but well co-ordinated work of research, of education and of economy, this country hopes to moderate, if not to solve, the difficult problems of heating, and, furthermore, to contribute in experience and study to the work already achieved by other civilised countries, in this very important field of human activity.

RÉSUMÉ.

L'un des problèmes les plus difficiles qui se posent à l'Italie tant en matières économiques que politiques est peut-être bien celui des combustibles. Les ressources naturelles pauvres de l'Italie en minéraux et plus particulièrement en combustibles solides et liquides ne peuvent satisfaire aux besoins de l'industrie; ainsi, en 1926, l'importation du charbon s'élevait à 14.000.000 de tonnes et celle de l'huile à 1.000.000 de tonnes. Malgré l'utilisation beaucoup plus intense des forces hydrauliques considérables de l'Italie, ces chiffres dépassent sensiblement ceux d'avant-guerre.

Dans ces conditions il est évident que le travail à accomplir par les echniciens italiens avec le concours du gouvernement et des industriels est en premier lieu un travail de recherches scientifiques et d'éducation professionnelle, afin d'obtenir l'utilisation la plus parfaite des combustibles indigènes et importés. Les auteurs donnent un aperçu des divers travaux entrepris dans ce but par les institutions compétentes et tout spécialement par l'Ecole polytechnique de Milan.

THE CONSTITUTION OF COAL

TECHNICAL COMMITTEE, FUEL CONFERENCE, 1928.

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RÉSUMÉ

Introduction

Coal is a conglomerate rock of vegetable origin. Animal remains have played an inappreciable and wholly incidental part in the formation of coal. Coal contains inorganic material, but this can be regarded as accidental impurity, even that small amount of so-called "inherent" mineral matter which is derived from the original mineral constituents of the plants from which the coal was formed; for there is no evidence that these constituents have played any part in the processes of coal-formation, however important their function may have been during the life of the plants.

The purely organic material, coal, is composed of carbon, oxygen, hydrogen, nitrogen, and sulphur, with traces only of other elements, such as phosphorus and arsenic (which may or may not be part of the coal-substance proper). No coal is of a precise, homogeneous composition. Variations in the proportions of the constituent elements, and in their modes of combination, account for the many varieties of coals.

In order that the different varieties of coals may be utilised most efficiently it is necessary to know, for each variety, not merely the proportions of the constituent elements, but their mode of combination, so that the true composition of the conglomerate can be gauged. Such knowledge has been hard to attain, and has but recently been forthcoming. In the past, therefore, in default

of such knowledge, the utility of different coals has been judged mainly by some specific, measurable quality that they possess, such, for example, as their calorific value or their contents of "volatile matter." No doubt the close dependence of such qualities on some fundamental property enables them to be used with some success to assess the value of a coal. For accurate classification, however, more reliance is placed on knowledge of the elementary composition of the coal, despite the fact that knowledge solely of the proportions in which the elements are present can give no clue to their mode of combination.

As examples of the value of knowledge of the ultimate analyses of coals, it has been found (Seyler[1]) that their general properties are dependent mainly on their carbon-contents, whilst, for a given carbon-content, the hydrogen-content determines other properties, such as the yield of "volatile matter" on heating. Coals with similar properties are not found at haphazard amongst a number having widely different compositions, but are grouped together by reason of similar ultimate analyses. Nevertheless, the correlation of the ultimate compositions of coals, from all sources, with their properties is far from complete, and, as far as it goes, is not as precise as could be desired. Reasons for this appear when the constitution of coal is studied more closely.

Coal

The term *coal* is conveniently restricted in normal British usage to the black varieties of technical importance. Elsewhere, the term may be, and is, extended to include such fuels as lignites and brown coals, when the deposits are of such an extent and nature as to be of value commercially. Carbonaceous materials, such as peats at the one end of the scale of carbon-contents, and graphites at the other, are not usually referred to as "coals." Nevertheless, by reason of the close relationship that exists between them, it is desirable to consider them in any discussion of the constitution of coal. The relationship between successive members of the series peats, brown coals, lignites, bituminous coals, anthracites and (perhaps) graphites has long been recognised. Each is derived from purely vegetable accumulations. Each covers a closely graded range of materials, and there is no sharp line of demarcation as between one member and the next.

From Peat to Anthracite

There has thus naturally arisen a belief that the "coal" fuels

form a continuous series in which the individual members differ one from another, not because of differences in the materials from which they were originally formed, nor even because of differences in their mode of formation, but because they represent successive stages in a slow process of "coalification." This "peat-to-anthracite" theory, or modifications of it, is now widely held, though it has been hotly debated in the past.

Microscopical Evidence. Evidence in support of the peat-to-anthracite theory is to be found in the readily demonstrable similarity of type amongst the materials from which the fuels were formed. Aside from such preferential accumulations of certain types of plant structures as characterise a few special coals, similarity in the structures and in their distribution has been demonstrated, for example, by Thiessen[2] as between the peats, brown coals, and bituminous coals of North America; and by Seyler[3] as between the bituminous coals and anthracites of Great Britain. The persistence, changed little by decay, of the same types of resistant plant tissues, such as spore exines and cuticles, is a feature common to all members of the series. Resins also, though not so resistant, have been shown (by David White[4], for example) to persist in almost their original physical forms throughout the series up to, at least, the semi-anthracite coals.

Chemical Evidence. There is a similarity in the chemical nature of the materials of which each fuel is compounded. The noticeable differences in properties between successive members of the series can be related, chemically, to minor changes in the external groupings of the compounds present. The internal structures of the molecules, whether the compounds are contained in a peat or an anthracite, appear to be much the same.

Analytical Evidence. Perhaps the most striking evidence of the continuity of the "coal" series is to be found in analytical data, such as have been adduced by Seyler[5], Ralston[6], Drakeley[7], and, more recently by Hickling,[8] in a noteworthy paper to which detailed reference must be made.

In conformity with the practice of the earlier investigators, Hickling has plotted, on rectangular co-ordinates, the elementary compositions of a large number of coals, and has shown that they occupy a narrow and continuous band over the whole range. The proportions of nitrogen and of sulphur appear to be constant throughout the range, varying but little from 1.5 and 1.0 per cent. respectively. The proportion of hydrogen in the coals (excluding

the cannels and the anthracites of highest carbon-contents) varies between 4.5 and 5.5 per cent., that is to say, by only 10 per cent.; on the mean value 5.0 per cent. The main variation in composition falls, therefore, on the carbon and the oxygen, and the variations in these two elements are nearly complementary. The carbon varies between 50 per cent. in the peats and 95 per cent. in the anthracites. Of this total variation of 45 per cent., 17 per cent. covers the groups of bituminous coals and anthracites.

The approximate constancy of the proportions of nitrogen, sulphur, and hydrogen is expressed by the narrowness of the band when the carbon-contents are plotted against the oxygen-contents of the coals. That the band should be narrow during the early (low-carbon) stages is an indication that the hydrogen-content of the original coal-forming materials did not vary much from a mean value. That the band should remain narrow up to the high-carbon end of the range is evidence that similar changes have operated in the formation of all the coals, for any marked variation in the character of the coalification would have resulted in products of markedly different hydrogen-content for a given carbon-content.

Thus, at any period during the coalification process, the changes appear to be of definite and unvarying character, dependent on the nature of the material, and not on the immediate conditions to which it is subjected. No doubt the immediate conditions would affect the rapidity of the changes.

A consideration of the distribution curve of coal analyses leads to a further suggestion. The curve, with carbon and oxygen percentages as axes, is at the outset nearly straight.

This suggests the gradual progress of but one kind of change. Assuming that the only kind of change, affecting ultimate composition, that can take place during progressive coalification is one involving loss of material, Hickling shows that the straight part of the distribution curve conforms with a gradual loss of carbon dioxide and water. The first straight portion of the curve ends at about 83 per cent. carbon, giving place gradually to a second straight portion over the range 89 to 95 per cent. carbon. This range covers but a slight loss of oxygen, with a proportionately higher loss of hydrogen, perhaps as methane. There appears to be a scarcity of coals of about 86 per cent. carbon-content (*i.e.*, at the juncture of the two straight portions of the distribution

curve), otherwise the distribution over the whole range is remarkably uniform.

The Formation of Coal

The validity of the peat-to-anthracite theory is not universally admitted. It is maintained, for example, by some geologists that the process by which any given coal has been formed has not necessarily been slow and gradual. If this is so, it follows that each class, or each individual, in the series has been the outcome of individual coal-forming conditions. For example, Strahan and Pollard[9] have suggested that the partial anthracitisation of the South Wales coalfield is due to differences in the nature of the deposited plant materials, a suggestion which has little to support it. Donath[10] has long maintained the view that for the formation of a bituminous coal a high temperature, involving partial distillation, is essential. A more moderate view, for which Erdmann[11] has made out a plausible (but by no means flawless) case, is that, whilst brown coals have resulted from coalification at normal temperatures, a temperature of at least 300°C. is required for the formation of a bituminous coal. Both these suggestions fail to account for the regular distribution of coals over the wide range of carbon-contents. It seems probable that, whilst a moderate increase of temperature can be regarded as one factor in the process of coalification, it would influence rather the rapidity of the process than its end-point.

A new theory of coal-formation, definitely opposed to the peat-to-anthracite theory, has recently been put forward by McKenzie Taylor[12], based on the following novel observations. Beneath an impervious alkaline layer, such as is formed by the hydrolysis of sodium alumino-silica soils, resulting from base-exchange, bacterial decomposition of vegetable débris proceeds rapidly and to completion, mainly with the elimination of oxygen. This is due chiefly to the maintenance of mildly alkaline conditions, the acid products first formed, which would otherwise bring the decomposition to a premature close, being continuously neutralised.

Whilst most peats are formed under aerobic conditions, the accumulation of acid products limiting the extent of the decay, examination of the roofs of bituminous coal and anthracite seams shows that they have, in general, an alkaline reaction, and that the coals have been formed under alkaline anaerobic conditions. This differentiates them from the lignites and brown coals, for an

examination of the roof of their seams shows that they have not been formed under anaerobic conditions and that they may have undergone incomplete bacterial decomposition and partial oxidation.

McKenzie Taylor's view of coal formation, therefore, is that the vegetable material has first undergone a peat-like decay, under aerobic, acidic conditions. The duration of the extent of this "peatification" determines the nature of the product. If the decay is checked, as under a normal acidic or neutral cover, the peat deposit may ultimately form a lignite, but it can never become a bituminous coal. On the other hand, if the material in its particular state of arrested peat-decay is maintained under alkaline, anaerobic conditions, *e.g.*, under a cover of alkaline soils, a secondary decomposition will ensue. This, the "coalification" process proper, is rapidly carried to completion, the end-product being a coal the nature of which depends not at all on the geological conditions, nor on time, temperature and pressure, but solely on the degree of "peatification" before "coalification" began, each class of coal, sub-bituminous, bituminous or anthracitic, being a definite end-product.

This view, whilst differing fundamentally from the peat-to-anthracite theory, where each coal is regarded as an intermediate product leading progressively to the anthracites of high carbon-content, yet accepts and attempts to explain the gradual transition in composition observable throughout the range. It is early to judge as to the ability of McKenzie Taylor's theory to explain the apparently restricted and uniform distribution of coal compositions, for more data are required, but of the importance of the theory there should be no question. The discovery of the part played by a cover of alkaline soil in determining the extent of bacterial decay of vegetable débris provides a solution to the hitherto puzzling differences observed in the degree of preservation of particular plant entities, both in peat and in coal. The pronouncement that bituminous coals have of necessity been formed under an alkaline cover demands close consideration.

To sum up, whatever may be the agencies which have advanced or limited the degree of "coalification," there can be no doubt but that the different members of the series, peat to anthracite, represent the effects of increasingly prolonged or increasingly severe conditions on materials generally similar.

The Coal-Forming Materials

The nature of the changes that have taken place during coal formation can be followed roughly from the changes in composition of the coal-forming materials. Thus, as Hickling has pointed out, the transition from the original materials to lignites has involved a proportionate loss of hydrogen, probably as methane; the bituminous coals differ from the lignites as their carbon-content increases in that they have suffered an increasingly greater loss of carbon dioxide and water; whilst to form the anthracites, elimination of hydrogen, perhaps as methane, has again occurred. More precisely, the nature of the changes can be deduced from a study of the behaviour of different plant entities under the coal-forming agencies.

The original plant materials, though botanically of widely varied source and form, were, from a chemical standpoint, not so diverse. For all varieties of plants are built up of materials of but few general types. The physical forms and the relative proportions of the few types may vary widely, but the chemical nature of each remains substantially the same.

Wide differences in the relative proportions of the main types of original plant materials might be expected to result in coals having different properties. Different properties of the coals might also be expected should there have been differences in the agencies at work, either during deposition or during decay, tending to eliminate some of the original types of plant materials and thus to give prominence to others. In each coal, in fact, there must be present, in varied proportions, compounds, each of its own particular composition, derived from each type of plant material. The elementary composition of the conglomerate must thus depend in a complicated manner on the proportions and individual compositions of each contributant. At first sight, therefore, knowledge of the elementary composition of a coal would not seem to offer much guide to its true nature. When, however, we study in detail the contribution to "coal" made by each type of plant materials, it becomes evident that their original complexity has not survived. It is found that there are in bituminous coals but three or four groups of compounds of markedly different character, namely, resins and hydrocarbons (waxes), the protective tissues of the plants that have resisted decay, and a readily oxidisable material that forms the bulk of the coal. This

simplification of the plant materials is already evident in peat, and thus presumably takes place during the early stages of decay.

Resins and Waxes. These normally form but a small part of the original plant material. Nevertheless, because of their resistance to bacterial decay and chemical change, they may bulk comparatively largely in the coal-forming material as other parts of it disappear through complete decay.

Protective Tissues. The waterproof protective coverings of plants, such as spore exines and the cuticles of stems and leaves, contain fatty substances which render them remarkably resistant to the processes of decay. These tissues, therefore, tend to accumulate in the coal-forming mass.

Cellulose and Lignin. These compose the cellular framework of the plants and originally form their greatest bulk. During bacterial decay, much of the cellulose disappears. The remainder of the cellulose, and most of the lignin, together with the carbohydrates and proteins of the cell-contents, ultimately form complex brown products, soluble in alkali, which can conveniently be classed under the term "ulmin compounds." Each of the different cell-forming materials appears to be capable independently, under suitable conditions, of forming "ulmin compounds"; whilst such compounds are readily formed by interaction between carbohydrates and nitrogenous compounds derived from the proteins. Although the ulmin compounds can be derived from such different materials, the separation of them into groups having markedly different characteristics has not been found possible, and it would seem that the process of "ulmification" reduces all the materials that form the plant cells to a common level. Since these materials form the bulk of the plants, the resultant ulmin compounds, despite wastage during decay, constitute the bulk of the decayed mass from which the coal is ultimately formed.

The Chemistry of Bituminous Coal

Soluble Constituents. By the extraction of a bituminous coal with suitable organic solvents, it is possible to dissolve parts of it. The extracts so obtained include hydrocarbons and materials resembling natural resins in composition and properties.

The hydrocarbons consist of complex saturated (paraffin and naphthene) and unsaturated liquid hydrocarbons, with smaller quantities of solid paraffins and higher aromatic hydrocarbons. Their amount varies between about 0.5 and 3 per cent. of the coal.

So far no relationship has been found between their quantity or composition, and the composition of the coal from which they are obtained. They are mainly derived, presumably, from the fatty oils and waxes of the original plants, whilst the smaller amounts of free hydrocarbons associated with the plant cuticles are no doubt included. None of the fatty oils and waxes has survived as such in bituminous coals, but waxes are often prominent in brown coals.

The resins extractable by solvents are similar in character to resin inclusions which can sometimes be separated from bituminous coals by hand. They are often less changed, as compared with present-day resins, than are some fossil resins. Their amount varies normally between 0.5 and 3 per cent. of the coal, but occasionally considerably more may be present.

Both hydrocarbons and resins, after separation from bituminous coal, distil almost unchanged on heating. It is also possible, by carefully regulated heating, to separate both these classes of compounds direct from bituminous coal by distillation alone.

Resistant Plant Tissues. Organic solvents leave untouched the spore exines and cuticles which abound in the majority of bituminous coals and form the most prominent objects to be seen under the microscope. Their presence is most readily shown, and their amount estimated, by careful oxidation of the coal as a whole, whereby the main bulk of it becomes soluble in alkaline solutions. The insoluble residue consists largely of spore exines and cuticles, with some resistant woody cell structures. The amount of this residue varies considerably, a bright coal (*e.g.*, a vitrain) perhaps yielding none, and a dull coal (a durain) as much as 20 per cent. by weight.

The spore exines and cuticles so separated from bituminous coal differ but little from the corresponding plant structures of to-day. Both spore exines and cuticles from coal are characterised by extreme resistance to decay and oxidation, and by the high proportion of tar which they yield on destructive distillation.

Ulmin Compounds. The bulk of the, normally, insoluble portions of bituminous coals can be so changed by carefully regulated oxidation as to become completely soluble in alkaline solutions. The materials recovered from the alkaline solutions are dark brown colloids, similar in many respects to the peat ulmins, but differing from them in that their carbon-contents are higher, and

they are more definitely acidic. They are oxidation products of the coal ulmins, analogues of the peat ulmins.

The chlorination of bituminous coal also yields compounds which can be related to similar chlorination compounds obtained from the peat ulmins. In fact, throughout the series, peat, brown coals, lignites and bituminous coals of increasing carbon-contents, chlorination yields, though with increasing difficulty, a graduation of compounds of similar characteristics. A study of the products of destructive distillation of each of the members of this series also reveals progressive differences in the character of the ulmin compounds that they contain.

This progressive relationship between the ulmin compounds in the different fuels, of which they usually form the major part, points to a progressive elimination of external groupings during coalification as the carbon-content of the fuel increases, such, for example, as would account for the progressive loss of carbon dioxide and water estimated from ultimate analyses by Hickling. As the carbon-content of the fuel increases, the ulmin compounds it contains become progressively more resistant to attack, whether by heat or by reagents. The increasing resistance to oxidation in particular affords a convenient measure of the degree of coalification of the ulmins. Such a measure is required when attempting a "rational" analysis of coal, for a complete specification of the quality of a coal must give expression to the degree of coalification of the ulmins as well as record their proportions and the proportions of hydrocarbons, resins, and resistant plant entities that the coal contains.

Banded Bituminous Coal

Whilst the effect of an increasing degree of coalification of the ulmins becomes apparent when comparing a number of coals of increasing carbon-contents, the extent to which differences in the relative amounts of the several ingredients of the conglomerate can effect the composition of a coal is well exemplified by a study of the macroscopic components, vitrain, clarain, durain, and fusain, of any given banded bituminous coal. The vitrain of a banded bituminous coal consists essentially of ulmin materials derived from the cellular structures of the plants. The durain is formed from mixed plant débris rich in resistant protective tissues, with a ground mass of ulmins similar, chemically, to those of the vitrain. The clarain is intermediate in character between the

vitrain and the durain; whilst the fusain represents cell structures which have resisted bacterial decay, probably owing to early aerial decay, and now appear as opaque carbonised fibres. The chemical differences between these components of a banded bituminous coal have been shown to be caused solely by differences in the proportions in which the several ingredients are mixed together in each, the ulmin compounds being of the same composition and character throughout the whole coal.

The Classification of Coals

To express the composition and quality of a coal fully it is necessary to specify the proportions of (1) hydrocarbons, (2) resins, (3) resistant plant entities, and (4) ulmin compounds that it contains, and to indicate the degree of coalification of the ulmin compounds. Analytical methods have been devised for obtaining this information.

Rational analyses of coals on these lines should lead ultimately to an ideal scientific classification of coals. The technical use of such a classification must then await experience of its application to coals of known characteristics, the various properties of the coals being correlated with their rational analyses. Such a correlation should be far simpler and more complete than is now possible between the properties of coals, and, for example, their ultimate or proximate analyses. For it is reasonable to assume that, in general, the properties of a coal will be the sum of the properties of its ingredients. From our present knowledge we can relate, broadly, certain properties of coal with the properties and proportions of one or other of their main ingredients. We can, for example, relate their yields of tar on distillation at a given temperature, with their contents of hydrocarbons, resins and plant entities, and the character of the tar with the relative proportions of each. The reactivity of a coal towards reagents, such as oxygen, depends mainly on the degree of coalification of the ulmin compounds. The caking-power appears to be dependent to a certain extent upon the nature and amount of each of the ingredients and on their reactions one with another during destructive distillation, but there is evidence that the quantity of hydrocarbons and resins and the quality of the ulmin compounds (*i.e.*, their degree of coalification) are of prime importance.

It is not likely that, for technical use, a classification based on rational analyses will displace those founded on, say, ultimate

analyses, though it may simplify and modify them. Experience has shown that the general properties of coals vary roughly with their ultimate compositions, so that it is possible to define "iso-vols" and "iso-cals," for example, in terms of carbon- and hydrogen-contents. The reason for this is, no doubt, that elementary composition follows rational composition quite closely, since the latter is expressed mainly by the proportions of the minor ingredients, and by the degree of coalification of the major ingredient, the ulmins. The degree of coalification of its ulmins greatly affects the elementary composition of a coal, in fact the carbon-content of a coal gives a rough measure of the degree of coalification of the ulmins it contains. On the other hand, variations in the amounts of the minor ingredients, which do not differ in elementary composition to a disproportionate degree from the rest of the coal, rarely affect more than slightly the ultimate analysis of the coal as a whole. For coals of the same type, therefore, a classification based on ultimate analyses has some theoretical justification. For coals of varied types, however, it demands considerable judgment in its use.

The grouping of coals according to their rational analyses has been successfully made with several chosen series, ranging from lignites to anthracites, and further data are being accumulated. The methods of rational analysis of coal, a description of which is given elsewhere, are but little, if any, more complicated than the usual methods. As experience is gained in their use, they will, no doubt, become routine tests to be employed either in substitution for, or to supplement, the usual proximate and ultimate analyses, when an unknown coal is being studied.

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RÉSUMÉ

La houille est une roche conglomerée d'origine purement végétale. Elle se compose principalement d'éléments organiques, à savoir de carbone, d'hydrogene, et d'oxygène, ainsi que de teneurs faibles et presque constantes en azote et en soufre. La houille varie beaucoup selon le caractère et la quantité des substances dont se compose le conglomérat; cependant il doit être possible d'établir un rapport entre les propriétés d'une houille et son analyse si cette dernière est donnée. En attendant, le classement des houilles a été basé sur des propriétés telles que la teneur en matières volatiles, le pouvoir calorifique et, plus recemment, la composition élémentaire. Ces propriétés, surtout la composition élémentaire, fournissent des indications précieuses sur l'utilité d'une houille aux différents modes d'emploi.

Plus on s'avance, dans la rangée des combustibles minéraux, de la tourbe vers l'anthracite, plus la teneur en carbone augmente et plus celle en oxygène diminue. En portant les teneurs en carbone et les teneurs en hydrogène en coordinées rectilignes, les compositions des combustibles se trouvent dans une zone très étroite et continue qui n'accuse aucune lacune sensible. La continuité de la série, mise en évidence aussi bien par les limites étroites de cette

zone et par la distribution uniforme des compositions sur toute sa longueur que par le fait connu du passage graduel des combustibles minéraux d'une catégorie à l'autre, a donné appui à la théorie de la formation de la houille dite la théorie "de la tourbe à l'anthracite." D'après cette théorie il y a une altération continue et incessante de la matière houillifiée. Une étude, récemment effectuée sur l'influence exercée par le caractère du dépôt sédimentaire de recouvrement sur la vitesse et l'étendue de la décomposition bactérienne du dépôt végétal, a donné à penser qu'il sera nécéssaire de renouveler la question, déjà discutée, de l'admissibilité de cette théorie.

Le fait que la zone représentant graphiquement les compositions de combustibles accuse des limites étroites, est dû, en premier lieu, à ce que le caractère chimique du gisement originel du conglomérat végétal est sensiblement uniforme et, deuxièmement, à l'uniformité des altérations qui ont lieu après le dépôt de la matière. La première transformation est l'ulmification des parois et du contenu des cellules. Les produits finals de cette transformation de la matière première sont les ulmines, substances de types très variés, qui constituent une catégorie pas (encore) nettement divisible en groupes. Cette ulmification peut être presque complète. Les résines, les cires, et les tissus protecteurs de caractère gras résistent à cette transformation. Plus tard la matière subit la houillification ce qui comporte principalement une perte, de la matière ulmique, d'anhydride carbonique et d'eau. Les autres substances ne subissent presque pas d'altération, même dans les houilles les plus fortes en teneur de carbone.

Etude chimique de la houille bitumineuse. Quand on soumet la houille au traitement par les solvants organiques, on obtient des hydrocarbures (provenant principalement de cires) et des résines. Moyennant une distillation très soignée il est possible de séparer, de la houille, des substances semblables. L'oxydation lente du residu insoluble le rend en grande partie soluble en milieu alcalin. La partie insoluble consiste essentiellement en enveloppes de spores et en cuticules. Ces dernières ne diffèrent guère des enveloppes de spores et des cuticules actuelles. On retrouve aussi du tissu ligneux non altéré. La matière soluble en milieu alcalin a toujours le même caractère, quelle que soit la houille dont elle provient. Cette substance, qui est une ulmine oxydée de la houille, accuse une parenté étroite avec les ulmines de la tourbe. Ces faits, ainsi que ceux qui ont été mis en évidence par l'étude des produits de distillation de la houille et de l'action exercée par les réactifs sur les diverses sortes de houilles, montrent que la fraction importante d'une houille normale consiste en matière ulmique apparentée aux ulmines de tourbe.

Ce constituant ulmique de la houille n'est pas de composition ou de propriétés constantes. Au fur et à mesure que la teneur en carbone augmente, la réactivité générale, comme, par exemple, la tendance de s'oxyder, diminue. La composition et les propriétés de cette matière ulmique, dont se compose la masse principale de la houille, détermine, pas tout à fait mais presque, la composition, et, à un moindre degré, les propriétés de la houille. Les propriétés des matières extractives et des tissus résistants dont la composition ne varie pas ont une influence beaucoup moins importante sur la composition de la houille. Leur influence sur le caractère de la houille est plus marquée et se montre plus nettement dans les constituants macroscopiques de la houille, à savoir, dans le vitrain, le clarain, le durain, et le fusain.

Pour préciser exactement la composition et la qualité d'une houille il faut préciser les proportions (1) des hydrocarbures, (2) des résines, (3) des éléments de tissus végétaux non altérés qui sont mélangés aux substances ulmiques, et indiquer le degré de la houillification des substances ulmiques.

On a imaginé des méthodes analytiques pour fournir ces renseignements. Un classement scientifique des houilles, établi sur ces principes, serait idéal et mènerait à une corrélation complète entre les propriétés et la composition des houilles. En attendant, la composition élémentaire est de nature à fournir des indications précieuses et commodes sur les propriétés des houilles, pourvu qu'on l'emploie prudemment et qu'on ne l'applique qu'aux houilles de structure analogue.

L'EMPLOI DES COMBUSTIBLES AUX PAYS-BAS

(THE USE OF FUEL IN THE NETHERLANDS)

L'INSTITUT NATIONAL NÉERLANDAIS POUR L'ÉCONOMIE DES COMBUSTIBLES

F. C. WIRTZ

*Paper No. A*15

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RÉSUMÉ

Par suite de leur situation géographique, les Pays-Bas peuvent facilement obtenir des combustibles des deux grands centres houillers en Angleterre et en Allemagne, et en outre une grande partie du charbon nécessaire est produite dans le pays même, savoir dans les mines du Limbourg.

La Production

La production de ces charbonnages a augmenté considérablement au cours des dernières années. On peut s'en rendre compte à l'aide de la statistique des mines qui indique qu'en 1926 la quantité de houille extraite s'élevait à 8.509.501 tonnes, tandis qu'en 1925 elle n'était que de 6.848.567 tonnes, ce qui constitue une augmentation de 24% en une seule année.

La quantité totale produite en 1926 peut être répartie comme suit:

13,6% de houille ayant une teneur en gaz de moins de 10%;
33,5% de houille ayant une teneur en gaz de 10 à 15%;
4,0% de houille ayant une teneur en gaz de 15 à 20%;
48,9% de houille ayant une teneur en gaz de plus de 20%.

Ce tableau montre que, d'une part, on extrait surtout du charbon ayant une teneur en gaz de moins de 15% et qui, sous le nom d'anthracite, est employé pour le chauffage des maisons; d'autre part, on produit de la houille riche en gaz, qui constitue la matière première pour la fabrication du coke, qui est connu pour sa bonne qualité et qui est même exporté à l'étranger.

L'Importation

L'importation de l'étranger comporte, outre les mêmes sortes de houille que celles produites dans le pays même, surtout le charbon riche en gaz employé dans les usines à gaz et venant surtout d'Angleterre, et de la houille allemande pour l'alimentation des chaudières à vapeur. On importe également une quantité pas très grande de combustibles de Belgique. L'importation totale de houille, de coke et de briquettes de houille et de lignite se répartit, pour l'année 1927, comme suit:

Allemagne	75,5%
Angleterre	19,8%
Belgique	4,7%

La Consommation

Quant à la consommation de combustibles aux Pays-Bas, elle est donnée par la somme du solde d'importation et de la propre production. On obtient ainsi les chiffres suivants:

Solde d'importation	3.115.722 tonnes	(27%)
Propre production	8.509.501 tonnes	(73%)
Total...	11.625.223 tonnes	(100%)

La consommation augmente continuellement depuis 1920, mais le développement de la production est encore plus fort, surtout grâce aux Mines de l'Etat. Aussi le solde d'importation baisse-t-il toujours.

Le coke est produit aux Pays-Bas par les fours à coke des Mines de l'Etat et par les installations à Sluiskil et à Maastricht, ainsi que par l'Entreprise Néerlandaise des Hauts-Fourneaux et Aciéries à Ijmuiden; si l'on y ajoute le coke des usines à gaz, on obtient un total de 1.794.164 tonnes. Il existe donc, entre le coke employé, le solde d'exportation et la production, la relation suivante:

Production	1.794.164 tonnes	(161%)
Solde d'exportation	678.462 tonnes	(61%)
Quantité consommée	1.115.702 tonnes	(100%)

En 1926, la consommation de houille (y compris les briquettes) et de coke s'élevait donc à 11.625.223+1.115.702=12.740.925 tonnes, dont 81% étaient produits dans le pays même.

La quantité totale employée peut être répartie sur les groupes suivants:

	tonnes
1. Industrie (y compris la navigation intérieure, la pêche du poisson, etc.) ...	6.004.084
2. Chauffage des habitations	2.400.000
3. Centrales électriques	1.350.000
4. Usines à gaz	1.191.110
5. Navigation maritime Néerlandaise ...	936.631
6. Chemins de fer et tramways	859.100
	12.740.925

Dans ce tableau, les postes 2 à 6 ont tous augmenté par rapport à l'année 1925. Le poste No. 1 a été déterminé comme différence de la consommation totale et de l'ensemble des postes 2 à 6; il a diminué par rapport à l'année 1925.

Le Chauffage Des Maisons

Il est impossible de déterminer avec sécurité de quelle manière la consommation des différents groupes variera dans les prochaines années. Pourtant, pour quelques-uns, on peut prévoir s'il faudra s'attendre à une augmentation ou à une diminution. Ainsi, pour le *chauffage des maisons*, on peut s'attendre à une augmentation, d'une part à cause de l'accroissement de la population, qui est d'environ 100.000 habitants par an, et d'autre part par suite d'un chauffage plus intense; cette perspective est importante au point de vue des débouchés pour le coke et le charbon à faible teneur en gaz. Ce dernier combustible est employé de plus en plus à côté du coke, tant pour les poêles que pour les chaudières de chauffage central.

Les Centrales Électriques, Etc.

Le groupe des *centrales électriques* demandera aussi une plus grande quantité de combustibles, non seulement à cause d'une consommation grandissante d'énergie électrique de la part de l'industrie et

des personnes privées, mais aussi par suite de l'électrification des lignes de chemins de fer et de tramways. Par conséquent ce dernier groupe, comprenant les *chemins de fer et les tramways*, emploiera à l'avenir une quantité moindre de combustibles. L'emploi croissant du gaz pour le ménage et l'industrie causera probablement aussi une augmentation de la consommation de combustibles pour le groupe des *usines à gaz*. D'autre part, ce développement sera retardé par les efforts que l'on fait pour distribuer directement, dans les communes environnantes, le gaz produit dans les fours à coke des Mines de l'Etat, et de l'Entreprise Néerlandaise des Hauts-Fourneaux et Aciéries à Ijmuiden. Ce gaz est déjà distribué actuellement dans un certain nombre de communes à raison d'environ 6,5 millions de mètres cubes par an, et des négociations déjà assez avancées ont été entreprises avec d'autres communes pour distribuer encore 18,5 millions de mètres cubes par an.

La Navigation Maritime

Le cinquième groupe, concernant la *navigation maritime*, a montré, abstraction faite d'une petite diminution en 1923, un développement régulier de la consommation, auquel on pourra s'attendre également à l'avenir, étant donné que la navigation se développe considérablement aux Pays-Bas. Il est vrai qu'au cours de ces dernières années, les grandes compagnies de navigation se sont occupées spécialement de l'économie des combustibles, afin d'en diminuer la consommation, de sorte que ces efforts se feront certainement ressentir.

L'Industrie

Quant au premier groupe, *l'industrie*, il est difficile de dire beaucoup à ce sujet. D'une part l'industrie se développe de plus en plus, ce qui pourrait faire prévoir une augmentation de la consommation de combustibles; mais, d'autre part, cette influence est contrebalancée par la tendance d'acheter la force motrice sous forme d'énergie électrique et de mieux contrôler le rendement du charbon consommé.

En outre, l'emploi des combustibles sera limité non seulement par le contrôle du rendement des installations, mais aussi par l'examen de leur qualité. Ce dernier point se manifeste par la tendance croissante à acheter les combustibles suivant leur *analyse chimique*. Celle-ci se fait de plusieurs manières très différentes.

Pour le service des chaudières à vapeur, on prend souvent la somme de la teneur en humidité et en cendres comme index, et le prix

d'un certain combustible est augmenté ou diminué, suivant que cette somme est inférieure ou supérieure à la valeur considérée comme normale pour ce genre de combustible.

D'autres fabriques font varier le prix suivant la teneur en humidité et celle en cendres indépendamment. En outre, à la place de ces deux données, on peut aussi se baser sur la valeur calorifique.

A côté de ce mode rationnel de déterminer le prix en fonction de la qualité, il arrive aussi que l'on se borne à une réduction de prix en cas de qualité inférieure; suivant ce dernier système, il n'y a pas d'augmentation de prix en cas de meilleure qualité, ce qui n'est évidemment pas juste en principe.

Pour donner une idée de la mesure dans laquelle on fait des achats suivant des analyses chimiques, notons qu'environ 52% des combustibles employés par les 19 principales centrales électriques des Pays-Bas ont été achetés suivant ce système. En outre, presque tous ces services font exécuter régulièrement des analyses. Celles-ci concernent généralement la teneur en humidité, en cendres et en matières gazeuses, ainsi que la valeur calorifique; dans quelques cas on détermine encore la teneur en soufre, le point de fusion des cendres et la cohésion pendant la combustion.

Parmi l'industrie privée, ce sont surtout lesgran des entreprises qui fixent des règles pour la qualité du combustible et qui déterminent le prix en conséquence.

Parmi les usines à gaz, qui sont presque toutes des entreprises communales, plusieurs qui produisent ensemble environ la moitié de la quantité totale achètent les combustibles suivant le système d'analyse. Toutefois, il n'y a pas de méthode fixe à ce sujet. Généralement on stipule une teneur en cendres maximale par rapport à la qualité du coke. D'autre part, on prescrit encore la teneur en humidité et en matières gazeuses. L'une des grandes fabriques calcule le prix de la manière suivante: pour chaque pourcent de teneur en gaz de plus ou de moins que la valeur garantie, le prix est augmenté ou diminué de 2 %. Si cette teneur est inférieure à la valeur garantie de plus de 2%, la diminution de prix, pour chaque pourcent de différence, est de 4%. Pour chaque pourcent de teneur en cendres de plus ou de moins que la valeur normale, le prix est diminué ou augmenté de 1% respectivement; si la valeur normale est dépassée de plus de 2%, le prix est réduit de 2% pour chaque pourcent de différence.

En cas d'achat suivant analyse, le vendeur et l'acheteur prennent chacun un échantillon d'une manière aussi exacte que possible,

puis ils le font examiner dans leur propre laboratoire ou dans un autre, de sorte que pour obtenir des résultats bien correspondants entre eux, il est très important d'unifier les méthodes d'épreuve. Dans ce but, l'Institut National Néerlandais pour l'économie des combustibles a émis, en collaboration avec des représentants des laboratoires, des gros consommateurs et des fournisseurs de combustibles, des prescriptions pour la détermination de la teneur en cendres, en humidité et en gaz. Ces prescriptions sont observées à peu près généralement aux Pays-Bas, de sorte que l'examen d'un même échantillon dans différents laboratoires donne des résultats qui correspondent bien entre eux, surtout en ce qui concerne la teneur en gaz.

L'achat suivant analyse présente une difficulté, en ce sens que la nécessité de prendre un échantillon de combustible d'une manière convenable entraîne des frais importants, surtout lorsque cela doit avoir lieu à l'endroit de livraison et que le fournisseur tient a y être représenté. Dans certains cas, s'il est certain que l'acheteur prendra l'échantillon d'une manière bien appropriée, le fournisseur se contente de lui laisser ce soin; toutefois, ces cas ne sont qu'exceptionnels.

La prise d'un échantillon d'une manière satisfaisante est une opération coûteuse, de sorte qu'il faut toujours faire un compromis entre la justesse de l'échantillon et les frais qui en résultent. L'Institut National Néerlandais pour l'économie des combustibles a émis également des prescriptions à cet égard, afin d'attirer l'attention sur tous les facteurs dont dépend l'exactitude. Chacun peut alors décider dans quelle mesure il voudra s'écarter de ces prescriptions complètes, et se rendre compte de la diminution d'exactitude qui en résultera.

RÉSUMÉ.

This paper gives first an estimate of the amount of fuel produced and consumed in the Netherlands during the last few years, and then the different purposes for which the fuel is used. It is shown that the production of coal from the mines in the Netherlands has recently reached a considerable figure, while at the same time the increase of the use of power in various forms has opened up a very encouraging prospect for the future. In every direction there is a tendency to increase the output of caloric installations, and the practice of submitting fuels to an anlaysis is greatly on the increase. The Netherlands National Institute for Fuel Ecomony has issued standard specifications, both for a chemical analysis and for the best methods of sampling.

THE CLASSIFICATION OF COAL

U.S. BUREAU OF MINES

A. C. FIELDNER

Paper No. A16

CONTENTS

METHOD OF ORGANISATION — METHOD OF WORKING — SCIENTIFIC CLASSIFICATION—USE CLASSIFICATION—MARKETING PRACTICE—CONCLUSION—RÉSUMÉ

Introduction

Adequate and uniform classification is fundamental to progress in the preparation and utilisation of fuels. This self-evident fact needs no amplification at a fuel conference, where the first division of each of the programmes for gaseous, liquid, and solid fuels covers composition and classification. These two subjects are closely related, so that classification should depend principally on composition. The first step in the development and use of any substance is the accumulation of knowledge concerning its composition and other properties. The second step is the reduction of this unorganised knowledge to a science by proper classification. Gaseous fuels are homogeneous mixtures of simple chemical compounds which can be identified and their relative proportions determined. Liquid fuels are likewise homogeneous fluids in which the chemical family groups, at least, can be recognised and determined. Gaseous and liquid fuels are, therefore, readily classified on the basis of composition and simple physical properties.

Solid fuels, on the other hand, are heterogeneous mixtures. Coal, in particular, is a conglomerate of diverse substances which vary greatly in origin, constitution and composition. This diversity of composition is responsible for the widely different properties of various classes of coal. One coal, on heating in a retort, will melt

and form coke, whereas another will merely char; one coal gives off large quantities of gas and smoke, while another burns smokelessly and yields but little gas. We know in a general way that these properties are related to the composition and constitution of the coal. We do not know the exact relationship, certainly not enough for complete classification. The problem of coal classification, therefore, is much more difficult than classification of either gas or oil, and it is more important, for without classification our accumulated knowledge of origin, composition, constitution, and properties will pile up in useless chaos. The scientific use of coal requires a scientific classification, which should be a world classification, so that research workers, engineers, and others dealing with coal may use a common language. It is in recognition of this need that the writer has taken this opportunity of presenting a report of the work of the American Engineering Standards Sectional Committee on the Classification of Coal, and the Committee's programme for developing a standard system for classifying North American coals.

Method of Organisation

The Coal Mining Institute of America referred to the American Engineering Standards Committee a system for the use classification of coal, proposed by Geo. H. Ashley,[1] State Geologist of Pennsylvania, and thus brought about the entry of the Committee into the field of coal classification. The American Engineering Standards Committee called a meeting at Pittsburgh in November, 1926, inviting representatives of various professional societies, industrial, educational, and governmental organisations, to consider what action, if any, should be taken on the Ashley system. The Pittsburgh meeting was well attended and strongly in favour of taking up the whole question of both scientific and use classification of North American coals, including the various ranks from lignite to anthracite. The American Society for Testing Materials was recommended as the sponsor organisation to form the sectional committee according to the rules of the American Engineering Standards Committee. These rules provide that "The personnel and composition of each sectional committee shall be authoritative and adequately representative of the various interests concerned in the standard or group of standards, for

[1] Ashley, Geo. H., *A Practical Classification of Coals*: Proc. Coal Min. Inst. Am. (1923), pp. 29-36. *A Use Classification of Coal*: Trans. Am. Inst. Min. & Met. Engrs. (1920), vol. 63, pp. 782-796.

the formulation of which the sectional committee is responsible."

Following this meeting the American Society for Testing Materials proceeded with the organisation of the committee. Invitations to appoint representatives were sent to the various trade organisations interested in the production, distribution, and consumption of coal, to professional, scientific, and technical societies, and to governmental organisations interested in coal classification. The organisation meeting of the committee was held in Philadelphia on June 10, 1927. Officers were elected, regulations adopted, and general plans for carrying out the work were outlined.

Following the organisation meeting, the membership of the sectional committee was completed. The total membership of twenty-eight consisted of eight producers, two distributors, nine consumers, and nine members representing general and scientific interests.

Method of Working

Obviously, a committee of twenty-eight is too large for effective operation. Therefore, three technical committees of ten to twelve members have thus far been organised; these are on Scientific Classification. Use Classification, and Marketing Practice. The technical committee on scientific classification was requested to formulate a system of coal classification based on chemical and physical properties and with reference to origin and constitution. The technical committee on use classification was charged with developing a system of classification if possible, based primarily on the uses of coal and commercial practice; this system is to be correlated with the scientific classification, as far as possible and desirable. The technical committee on marketing practice was formed to collect and collate information on commercial practice for the benefit of the classification committees.

The first meetings of the technical committees were held on November 17, 1927, and the first informal progress reports were submitted to the sectional committee at the annual meeting held on March 28, 1928. The reports showed that each of the committees had made a satisfactory beginning in planning programmes, and assembling necessary fundamental data for carrying out their work. A brief review of these working plans will be of interest to persons concerned with coal classification in other countries, and may serve to enlist their informal co-operation with the American

committee. It is conceivable that other coal-producing countries may also organise similar committees which may eventually co-operate in agreeing on a uniform system for all countries.

Work of the Technical Committee on Scientific Classification

The technical committee on scientific classification accepted the instructions of the executive committee, and agreed that a scientific system for the classification of coal should be developed primarily on the basis of chemical, physical, and geological considerations. The work of the committee was organised under the following sub-committees :—

Sub-committee I—On nature, location, and mode of occurrence of types of American coals.

Sub-committee II—On origin and composition of coal, and methods of analysis.

Sub-committee III—On present and proposed systems of coal classification.

M. R. Campbell, of the U.S. Geological Survey, chairman of Sub-committee I, formulated an outline of what he considered to be natural divisions of coal and allied mineral fuel substances. These divisions are the various stages through which coaly matter passes in its progressive transformation from peat to anthracite.

Since the metamorphism of coal is progressive, one would expect a continuous variation in the chemical and physical properties, with no sharp boundaries for setting up divisions. Under these conditions the division into ranks would be a purely arbitrary matter of selecting division points on the scale of some continuously varying properties. But, as a matter of fact, coals from all parts of the scale of rank do not occur in American coal deposits. Certain groups of coals vary over limited portions of the scale. Gaps exist between these groups in some cases, whereas in others the groups overlap. The logical rank divisions for American coals are on the boundaries of those groups which have a general similarity of properties other than the continuously varying property chosen as the scale of rank. This grouping may be considered natural for American coals, but not for coals of other countries, in which other parts of the scale of rank predominate. With these considerations in mind, Campbell has set up the following nine classes, or ranks, of coal and allied fuel substances :—

TABLE I—LIST OF CLASSES OR RANKS RECOGNISED

Class or Rank	*Equivalent term in present U.S. Geological Survey classification*
A	Peat
B	Lignite
C	Sub-bituminous
D	Bituminous, low rank
E	Bituminous, high rank
F	Semi-bituminous
G	Semi-anthracite
H	Anthracite
I	Super-anthracite

The application of chemical and physical criteria to these classes will require extended work by the committee. Proximate and ultimate analyses, calorific values, and physical properties are all of importance. For a beginning, Campbell has confined himself to the proximate analysis and the calorific value of the dry ash-free coal, and to certain physical properties, such as the tendency to slack on exposure to the atmosphere. Table II gives a summary of these criteria.

TABLE II.

ANALYTICAL LIMITS AND PHYSICAL CRITERIA FOR VARIOUS RANKS OF COAL

Class or rank.	Proximate analysis percentage in ash-free coal.			Calorific value of ash-free coal, B.Th.U.	Physical properties and occurrence.
	Moisture.	Vol. matter.	Fixed carbon.		
A	90–80	—	—	—	Peat.
B	50–32	25–30	28–37	6,400–8,300	Slacks freely on weathering; non-coking; northern part of Great Plains and Gulf coastal area.
C	32–12	32–38	36–50	8,550–11,800	Slacks considerably on weathering; non-coking; Western States and possibly certain coal fields, Iowa, Illinois, Missouri, Western Kentucky, and Indiana.
D	12–5	39–42	49–53	12,000–13,600	Slight or no slacking on weathering; may be coking; all coal-bearing States except the Dakotas.
E	5–35	40–22	55–75	14,000–15,000	No slacking properties; often coking; most abundant in Appalachian field, but also found in most coal-bearing States.
F	26–23	23–15	74–82	15,200–15,300	Friable; coking; nearly smokeless; central Pennsylvania; New River-Pocahontas field; Fort Smith field of Arkansas and Oklahoma.
G	Fuel Ratio (F.C/V.M.) from 4·0–10·0.				Less hard and less lustrous than typical anthracite; near Lykens, Bernice, and Carbondale in Pennsylvania; Meadow Branch field of West Virginia; and Valley field of Virginia.
H	All Pennsylvania anthracite with fuel ratio over 10·0				Pennsylvania anthracite.
I					Resembles graphite; Rhode Island and southern Massachusetts. Local deposits due to metamorphism caused by volcanic dikes and sills.

The foregoing criteria of classes of coal in the rank scale apply to the ordinary ulmic or woody type of coals. Similar criteria will be worked out for cannel and boghead coals. Three types of coal are recognised, namely: (1) woody, xyloid, ulmic, or humic coals; (2) canneloid or spore coals; and (3) boghead or algel coals. The type represents the nature of the original coal-forming vegetation, and the rank represents the degree of transformation or metamorphism.

Sub-committee II, on origin, composition, and methods of analysis, is the authority on testing methods, both in describing existing methods and in developing new methods. This committee will be the source of information on the interpretation of old analyses, and will advise on what properties determinations can be made. Existing analytical data will be assembled by this committee. A preliminary report has been made which gives the probable errors and limits of accuracy of the American Society for Testing Materials, standard methods of analysis, and comments on the effect of changes made from time to time in the standard methods. Experiments are now in progress on the development of an accelerated slacking test for low-rank coals and lignites. These coals usually have a high moisture content and disintegrate or slack after mining. The slacking tendency has been considered characteristic of sub-bituminous coals and lignite in the U.S. Geological Survey method of classification.

Briefly, the slacking test consists of air-drying a 1,000-gram sample of 1 to 2 in. lumps at 30° to 35°C. for twenty-four hours, and then immersing the lumps in water for one hour; the water is then drained off, and the sample is again air-dried for twenty-four hours. The amount of disintegration is determined by sieving on an 8-in. wire-mesh sieve with $\frac{1}{4}$-in. square openings, and weighing the undersize and oversize. The percentage of undersize is a measure of the slacking characteristics of the coal. Results of preliminary tests are promising: a sample of Texas lignite gave 97 per cent. fines; a Wyoming sub-bituminous coal 84 per cent.; an Iowa low-rank bituminous 24 per cent; and high-rank bituminous coals, which are known not to slack, gave 3 to 10 per cent. fines.

One of the most important problems facing the analytical committee is the question of whether to use for classification the simple, dry, ash-free analytical values as ordinarily determined in commercial coal analyses, or the "unit" values as proposed by

Parr. Strict accuracy also demands special correction of the hydrogen and carbon determinations to eliminate that part of these elements which is derived from water of constitution in shale or clay and from carbonates. Tideswell and Wheeler,[2] and also Seyler,[3] favour such corrections. Our committee recognises the theoretical justification in favour of the corrections, but it also appreciates the practical difficulties of getting commercial laboratories to adopt the more complicated procedures. The committee is therefore approaching this question with an open mind, and proposes to make a thorough investigation of the problem. At the present time the simplest solution appears to be the removal of as much ash-forming material as possible by a float-and-sink separation of coal and free impurities. This procedure usually reduces the ash content to such a low amount that the error is small—small enough to be disregarded for purposes of classification.

Sub-committee III, on present and proposed systems of classification, of which H. J. Rose is chairman, is studying all of the more important methods which have been proposed for coal classification. Most of these systems are based either on the ultimate or proximate analysis of the coal. Seyler[4] has worked out a detailed system, based on ultimate analysis, which applies to the whole range of coal from lignite to anthracite. Ralston[5] applied the same method to American coals. By plotting the percentages of carbon, hydrogen, and oxygen of the pure coal substance, the variation of ultimate composition with other properties of the coal can be shown graphically.

The U.S. Geological Survey system[6] of classification is based on the rank (*i.e.*, degree of metamorphism) of the coal, as indicated by the proximate analysis and certain physical characteristics, such as the slacking tendency of the coal on exposure to the

[2] Tideswell, F. V., and Wheeler, R. V., *Pure Coal as a Basis for Classification.* Tech. Pub. No. 104, Am. Inst. Min. & Met. Engrs., March 1928.

[3] Seyler, Clarence A., *The Classification of Coal.* Paper presented at New York meeting, Feb. 1928, Am. Inst. Min. & Met. Engrs.

[4] Seyler, Clarence A., Proc. South Wales Inst. Engrs. (1900), Vol. 21, p. 483, *et seq.*; represented in Fuel in Science and Practice (1924), Vol. 3, pp. 15-26, 41-49, 79-83.

[5] Ralston, O. C., U.S. Bureau of Mines, Tech. Paper No. 93 (1915).

[6] Campbell, W. R., Prof. Paper 100 A, U.S. Geol. Survey (1917-1922): Proc. Int. Conf. on Bit. Coal. Carnegie Inst. of Tech., Pittsburgh, Pa., Nov. 1926, pp. 11-16.

atmosphere. This system is generally used by American Geologists, and has the advantage of simplicity. The ratio of fixed carbon to volatile matter (called "fuel ratio") is the principal criterion of the different classes. The fuel ratio decreases with the rank of the coal; however, the fuel ratio fails to differentiate between low-rank coals and lignites. Therefore, slacking and other characteristics are used for differentiation in the lower part of the scale of rank. The Parr[7] system of classification is in effect based on a combination of proximate and ultimate analyses, since the calorific value of coal depends on the ratios between carbon, hydrogen, and oxygen, as proved by the fact that the heating value of a coal can be calculated to within 1 or 2 per cent. from the ultimate analysis by Dulong's formula. Parr plots the "pure" or "unit" coal volatile matter against the "pure" or "unit" coal calorific value. The diagram obtained shows the rank of the various coals. Coals of similar properties occur in groups. The volatile matter is the dominating factor on the high-rank end of the scale, and the calorific value dominates in differentiating the low-rank end of the scale. The Parr system appears to have most of the advantages of the ultimate analysis system, without requiring the tedious ultimate analysis determinations, for which many commercial laboratories are not equipped. Most coal laboratories are now able to do accurate calorimetric work and to make correct proximate analyses.

Ashley's[8] system of use classification is based on proximate analysis and physical factors, and is essentially similar to the U.S. Geological Survey system, although the groupings are somewhat different and the "fuel ratio" limits for each group are not identical. The "use" part of classification consists of assigning limits of ash and sulphur within the different classes of rank, thus indicating the grade of the coal. Ashley also gives representative ultimate analyses of the different classes of coal, and specifies physical characteristics, such as "structure," "hardness," coking properties, flaming properties, etc. Ashley and Seyler have worked out complete systems of nomenclature for various coals.

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[7] Parr, S. W., *The Classification of Coal.* Jour. of Ind. & Eng. Chem., (1922), Vol. 14, p. 919.

[8] Ashley, Geo. H., *A Use Classification of Coal,* Trans. Am. Inst. Min. and Met. Eng. (1920), Vol. 63, pp. 782-796.

[9] Bull, 89, Topographic and Geological Survey, Commonwealth of Penna, (1926).

These four systems of classification discussed are the chief systems that have received attention in America. H. J. Rose is engaged in a thorough study of the systems and is developing a graphic method for comparing them. Enough work has been done thus far to show that the Seyler-Ralston and the Parr systems can be compared directly, and it is likely that the U.S. Geological Survey and the Ashley systems can also be compared, perhaps less directly, but nevertheless with sufficient accuracy to permit of setting up limits for a given group of coals of similar characteristics, so as to identify it in each of the four systems. It is proposed that the U.S. Geological Survey, the U.S. Bureau of Mines, and the Department of Mines of Canada, shall collect and analyse a large number of additional samples from unweathered coal beds to supply any deficiencies existing in analytical data on coals of questionable classification. From these comparisons the committee hopes to work out eventually the best combination of analytical and other criteria for a scientific classification of coal.

Work of the Technical Committee on Use Classification

The technical committee on the use classification of coal is charged with making a study of the possibilities in the development of such a classification, if desirable, possible, and equitable, based principally on the uses of coal and commercial practice, but also correlated with scientific classification in so far as is thought desirable or possible. One of the objectives of this committee is to determine how far the scientific classification may be of use in commercial practice. Another objective is to secure data on the different uses for coal and the requirements for these uses. To attain this end, sub-committees were appointed to obtain data on the following uses and types of coal :—

1. Gas making : water gas, coal gas, and producer gas.
2. Coke making.
3. Coal used in the brick and tile industries.
4. Coal used in the cement industry.
5. Coal used in the metallurgical industry.
6. Smithing coal.
7. Railroad coal.
8. Stationary steam generation.
9. Domestic bituminous coal.
10. Domestic anthracite coal.

Considerable information has been assembled by the sub-committee on gas coals, coal for water-gas generators, and coal for producer gas. Specifications and desirable characteristics for these classes of coal are outlined in the first report of this sub-committee.

The sub-committee on coals for stationary steam generation also has submitted a comprehensive preliminary report on the desirable characteristics of coals for hand firing, for different types of stokers used in steam power plants, and for pulverised fuel combustion. Obviously, no hard-and-fast rules can be laid down for such coals, since costs and available supply are important factors.

The task before the use classification committee is a large one, and several years will be required to assemble all the needed information.

Work of the Technical Committee on Marketing Practice

The technical committee on marketing practice is to collect and correlate information on marketing practice with reference to classification, and for the benefit of the other two technical committees. In order to collect data on marketing practice and classifications now in use, sub-committees were appointed to cover the various marketing areas of the country. These areas are as follow :—

1. Anthracite (all markets).
2. New England.
3. Coastwise (tidewater), export and bunkers, and Atlantic States inland.
4. North.
5. South.
6. South-western.
7. Rocky Mountains.
8. Pacific coast.
9. Central (east of Mississippi River).
10. Southern inland.
11. Lakes and North-west.
12. Canada, Eastern and Central.
13. Canada, Western.

Of these sub-committees, three have already completed comprehensive reports, namely, those on anthracite, the Pacific coast, and

the Rocky Mountains region. The data being obtained are proving to be particularly valuable to the use classification committee.

Conclusion

In conclusion, it may be said that the work of the American Engineering Standards Committee is now well under way. The project is of great magnitude and of the highest importance. In the organisation period the coal operators were not over enthusiastic, but now they are among the most active working members. After getting into the work they appreciated the fact that correct classification would prove a great aid to a better understanding between seller and buyer, and would result in directing each class of coal into the use for which it is most valuable.

The organisation of separate committees on scientific and use classifications promises to do away with much unprofitable argument in the progress of the work. It provides clean-cut objectives for each group, and permits the scientists to develop their ideas unhampered by commercial considerations. On the other hand, the engineers and commercial men concerned with producing, distributing, and using coal are able as members of the use classification committee to work out their ideas with the advice of the scientific men who compose a minority on the committee. The scientific committee consists chiefly of chemists, geologists, and paleo-botanists, but there is also included a minority of practical fuel engineers to keep the scientists from wandering into the field of impracticability.

After each of the two technical committees has reached a satisfactory conclusion in the work of classification, and has submitted a report, the entire committee will probably take steps to harmonise "use" and scientific classification as far as is possible. It is not unlikely that the final result will be a simple system of classification, both scientific and useful.

RÉSUMÉ

L'importance fondamentale d'une classification uniforme et complète des charbons et des minéraux alliés a amené la Commission sur les Étalons des Ingénieurs Américains (American Engineering Standards Committee) à organiser une sous-commission pour la révision et l'étude des méthodes courantes en vue de rédiger un système de classification applicable en général aux charbons et lignites de l'Amérique du Nord, et en même temps acceptable à tous ceux qui s'intéressent au problème des combustibles.

Une commission composée de 29 membres fut organisée au mois de juin 1927 sous les auspices de l'American Society for Testing Materials. Elle se compose d'un nombre à peu près égal de représentants des producteurs, des consommateurs et des intérêts généraux. Les organisations principales professionnelles, commerciales, éducatrices et gouvernementales ayant intérêt à la houille y sont représentées, comme le sont tous les points de vue du problème.

Le travail propre de la commission est confié à trois commissions techniques ayant à peu près 12 membres chacune. Les commissions et leurs charges sont comme suit:

(1) La commission technique pour la classification scientifique doit rédiger un système de classification basé sur les caractéristiques de la houille même, c'est-à-dire, sur ses qualités chimiques et physiques, sa constitution et son origine.

(2) La commission technique pour la classification basée sur l'emploi est chargée de l'étude des possibilités de développement d'un système basé principalement sur les emplois de la houille et sur la pratique commerciale, et en même temps coordonné au système scientifique autant que possible.

(3) La commission technique sur les méthodes de vente doit rassembler et coordonner les données sur les méthodes de vente, en tenant compte de la classification. Ces données seront employées par les deux autres commissions.

Ces trois commissions ont eu leurs premières réunions au mois de novembre 1927 et leurs deuxièmes au mois de mars 1928. Leurs programmes ont été rédigés et le travail a commencé. Des données complètes se rassemblent sur la composition chimique, sur les caractéristiques physiques et sur les traits géologiques des différentes catégories de charbon de l'Amérique du Nord. Tous les systèmes de classification proposés au passé et ceux actuellement en usage dans les différents pays font le sujet d'un examen rigoureux de leur utilité en déterminant les caractéristiques de la houille par rapport à sa conduite dans ses différents emplois. Une étude spéciale se fait des systèmes les plus importants basés sur l'analyse élémentaire comme proposés par Regnault, Gruner, Sayler, Grovt et Ralston, et ceux basés sur l'analyse immédiate comme proposés par Frazier, Campbell, Parr et Ashley. Les comparaisons faites jusqu'à présent indiquent que les deux systèmes, celui de l'analyse élémentaire et celui de l'analyse immédiate, peuvent être coordonnés et que les critériums limites analytiques d'un certain groupe de charbon ayant de semblables caractéristiques peuvent être inclus dans plusieurs systèmes de classification, permettant la translation d'un système à l'autre, au moins jusqu'à un certain point.

La commission croit que la classification scientifique des charbons doit se faire selon les deux considérations suivantes: tout d'abord, le type de houille, déterminé par la nature de la matière qui l'a produit; et puis, le "grade" de la houille, ce qui dépend du degré de métamorphisme de la matière houilleuse. Les types reconnus d'ordinaire sont: (*a*) les houilles ulmiques, humiques, xyloïdes et ligneuses, (*b*) les houilles grasse, demi-grasse, et (*c*) les bogheads et algels.

Chacun de ces types de houille peut varier de la houille brune ou lignite jusqu'à l'anthracite, selon le degré de transformation due aux permutations biochimiques et dynamiques.

Nous espérons que ce résumé de l'organisation et des buts de la commission américaine, avec laquelle coopère le National Research Council du Canada pour les charbons canadiens, donnera lieu à un mouvement ayant pour but une classification mondiale des charbons. Une telle unification est nécessaire pour mieux évaluer les résultats des études faites sur la houille dans les différents pays et pour éliminer les erreurs coûteuses dans le commerce international de la houille.

GENERAL REPORT ON SECTION A

THE COAL INDUSTRY
ECONOMIC AND GENERAL CONSIDERATIONS

JOHN ROBERTS

1 The following papers from Section A are dealt with in this Report :—

(*a*) "The Combustion of Brown Coal in the Australian Commonwealth," by the State Electricity Commission of Victoria (A2).

(*b*) "The Coal Industry in Austria," by Dr. A. Gstöttner (A3).

(*c*) "Proposals for the Technical Designations of Coal Characteristics," by the Gesellschaft für Wärmewirtschaft (A4).

(*d*) "A Study of Post-Carboniferous Coals," by Dr. Edgar Stansfield (A5).

(*e*) "Methods used for the Improvement of Lignites in Czechoslovakia," by J. Formánek (A6).

(*f*) "Methods of Burning Dutch East Indian Coals," by D. J. L. Coninck Westenberg (A8).

(*g*) "Korean Coals and their Utilisation," by Prof. M. Kamo (A9).

(*h*) "Notes on the Rational Use of Lignite in Roumania," by Joan Bujoiu (A10).

(*i*) "Utilisation of Low-Grade Fuels in U.S.S.R.," by Prof. L. K. Ramzin (A11).

(*j*) "Characteristics and Classification of Fuels in U.S.S.R.," by Prof. L. K. Ramzin (A12).

(*k*) "The Constitution of Coal," by Prof. R. V. Wheeler (A14).

(*l*) "The Use of Fuel in the Netherlands," by F. C. Wirtz (A15).

(*m*) "The Classification of Coal," by A. C. Fieldner (A16).

2 The majority of these papers are devoted to a discussion of the classification of coals, and the resources and methods of utilising low-rank fuels, which consist mainly of lignites and coals of Post-Carboniferous age.

Classification of Coals

3 Several authors draw attention to the need for a universal system of coal classification, which would embrace all coals—Carboniferous and Post-Carboniferous (A5)—and one which would satisfy the requirements of scientific investigators, technical users, and the commercial world. In his plea for such a system, Ramzin (A12) states: "I should like to express a wish regarding a certain unification both as regards methods of laboratory fuel investigation and also commonly employed terminology and symbols. When co-ordinating large numbers of analyses one constantly has to waste a tremendous amount of time deciphering individual analyses for the purpose of ascertaining whether the given values refer to moist or dry coal, whether gross or net calorific value is understood. . . . The ever-developing co-operation of all nations in the solution and elaboration of scientific problems . . . calls for an international unification of laboratory methods . . . as well as for a common language in the terminology and symbols pertaining to fuel investigation." He suggests that the World Power Conference should take the initiative in this problem, the solution of which would greatly facilitate the exchange of scientific and industrial experience.

4 In paper A4 proposals are made for the technical designation of coal characteristics, and there is included a record of the work done in Austria on the preparation of reference tables, with the suggestion that the Conference should endeavour to come to an international agreement on the matter. Standard specifications for analyses and sampling have been issued in the Netherlands (A15).

5 The desirability of devising an ideal classification system is also emphasised by Wheeler (A14), who considers that: "To express the composition and quality of a coal fully, it is necessary to specify the proportions of (1) hydrocarbons, (2) resins, (3) resistant plant entities, and (4) ulmin compounds that it contains, and to indicate the degree of coalification of the ulmin compounds. Analytical methods have been devised for obtaining such information. Rational analyses of coals on these lines should lead ultimately to an ideal scientific classification of coals. The technical use of such a classification must then await experience of its application to coals of known characteristics,

the various properties of the coals being correlated with their rational analyses."

6 The scientific, technical, and commercial aspects of coal classification are receiving attention in the investigations which have been undertaken by the American Engineering Standards Committee, as described by Fieldner (A16). This Committee, in conjunction with the American Society for Testing Materials, has appointed three technical committees to review the whole question. One committee is concerned with the scientific classification, whose function is to formulate a system of classification based on chemical and physical properties, and with reference to origin and constitution. A second committee is detailed to develop a system of classification based primarily on the uses of coal, and commercial practice, its work being correlated as far as possible with that of the scientific committee. The third, the Marketing Practice Committee, was formed to collect and collate information on commercial practice for the benefit of the classification committees.

7 The work has naturally been distributed among a number of sub-committees, as under :—

Committees.	*Sub-Committees.*
(*a*) Scientific Classification	Nature, location, and mode of occurrence. Origin and composition—Methods of analysis. Present and proposed systems of classification.
(*b*) Use Classification	Gas making. Coke making. Brick and tile industries. Cement industry. Metallurgical industry (coal used). Smithy coal. Railways coal. Stationary steam generation. Domestic bituminous coal. Domestic anthracite.

(*c*) Marketing Practice.

Sub-committees were appointed to cover the various marketing areas in the country—13 in all.

8 The work is now well under way. The project is of great magnitude, and of the highest importance. The committees have the active support of the coal producers, who now realise that correct classification will provide a better understanding between buyer and seller, and will result in directing each class of coal into the use for which it is most valuable.

9 The organisation of separate committees provides clear-cut objectives for each group, and permits the scientists to develop their ideas unhampered by commercial considerations. On the other hand, the engineers and commercial men concerned with producing, distributing, and using coal are able to work out their ideas with the advice of scientific men.

10 The Scientific Committee consists chiefly of chemists, geologists, and palaeo-botanists, "but there is also included a minority of practical fuel engineers to keep the scientific men from wandering into the field of impractibility."

"After each of the two technical committees has reached a satisfactory conclusion in the work of classification, and has submitted a report, the entire committee will probably take steps to harmonise 'use' and scientific classification as far as possible. It is not unlikely that the final result will be a simple system of classification, both scientific and useful."

As stated by Fieldner, "it is conceivable that other coal-producing countries may also organise similar committees who may eventually co-operate in agreeing on a uniform system for all countries."

11 It is gathered from the papers that lack of uniformity, if not confusion, exists in regard to the classification of lignitic coals, particularly in distinguishing between Brown Coals and Lignites (Formánek, A6).

Resources of Low-rank Coals

12 Approximately 68 per cent. of the estimated coal reserves in the United States (A5), and 98 per cent. of the Canadian resources are Post-Carboniferous, and of the total resources of

the world 50 per cent. consists of North American Post-Carboniferous coals. Only 5 or 6 per cent. of the United States production is of coal of this age, while of Canada's output 60 per cent. is Post-Carboniferous. It has been estimated that west of the 100th meridian the deposits contain 2,354,235,000,000 tons of coal, including the lignites of Texas and Arkansas. About 40 per cent. of this is lignite, and 42.3 per cent. sub-bituminous, the remainder being almost all bituminous. 70 per cent. of Canada's Post-Carboniferous coal is lignite.

13 Large deposits of lignite occur in Australia, both in Tertiary and in Trias-Jurassic rocks. The lignites of the Latrobe Valley area, dealt with in paper A2, are of Tertiary age. A borehole put down in the parish of Maryvale, near Morwell, passed through 780 ft. of coal in a depth of 1,019 ft., without passing completely through the coal measures.

14 Extensive deposits occur in Germany, and smaller fields are found in Czechoslovakia (A6), the U.S.S.R. (A12), Korea (A9), and the Dutch East Indies (A8). Other coals of low grade, such as inferior anthracites, occur in some of these countries, and are referred to in various papers.

15 Not all coals of comparatively recent geological age are of low rank, for, as Stansfield (A5) states: "It is safe to assume that, other things being equal, a Carboniferous coal is always of higher rank than a Post-Carboniferous coal. In other words, a comparatively undisturbed seam of Carboniferous coal, by mere passage of time and the pressure from superincumbent strata, has become more metamorphosed from the original vegetal matter than has an equally undisturbed seam of Post-Carboniferous coal, with its shorter time since deposition, and probably smaller pressure from superincumbent strata. This can be expressed by saying that of two coals of equal rank, but of unequal geological age, the newer coal must have been subjected either to the greater pressure due to the folding of the strata and the uplift of mountains, or to heat due to igneous intrusions or to lava flows." Evidence in support of this contention is furnished by Stansfield, as exemplified in the case of North American coals.

16 Even Eocene coals (A8) have, in places, been converted by volcanic agencies into anthracite.

Utilisation of Low-grade Fuel

17 The lignitic coals are non-coking, and are characterised by high moisture contents. These properties demand that special steps be taken in their utilisation, a matter which has received considerable attention in several papers.

18 *Combustion.*—Paper A2 describes fully the work done in Australia on the development of systems of burning brown coals of high-water content, up to 65 per cent. "In designing boiler plants intended to utilise brown coal in the raw state, many difficulties are experienced, due principally to the moisture present in the raw fuel, and the relatively low heat value of the combustibles in the coal. The moisture in the fuel results in an increase of the stack losses, with a corresponding decrease in the thermal efficiency, while the aggregate effect of the high moisture and low heat value of the combustible is that the grate area must be made correspondingly larger."

19 Several modifications have been introduced in boilers of various types, which are described and illustrated in paper A2, the heat balances of the boiler trials being given. The Yallourn brown coal, with 64 per cent. of moisture, presented much greater trouble than the Morwell coal of 50 per cent. water content. Many systems of pre-drying were tried. Mechanical step grates, used in conjunction with drying shafts, have proved successful.

20 It has been found that pre-drying the air for combustion has a beneficial effect. Similar results were obtained in tests on the combustion of brown coal of the Sub-Moscow region, and with Tcheliabinsk coal (A11), where the introduction of the hot blast increased the efficiency of the furnace.

21 Considerable work on the combustion of Eocene coals, containing up to 45 per cent. of volatile matter, has been carried out in the Dutch East Indies, as described by Westenberg (A8). Experiences in hand-firing and mechanical firing on various types of plants are recorded. Pulverised-fuel firing has proved successful with these coals, as well as with Korean anthracite (A9). The latter paper, however, deals chiefly with the low-temperature carbonisation of brown coals.

22 *Low-Temperature Carbonisation of Brown Coals.* Prof. Kamo (A9) gives a description of the Asorbus carboniser, designed

for the low-temperature treatment of brown coals, and includes tables of yields and the properties of the products. The coal is first screened; the undersize passes to one threaded drum, and the oversize through a separate chute to a smaller threaded drum, which revolves within the larger one. At the outlet of these, but within the retort proper, the coals are mixed, and then pass through the retort, being agitated by means of paddles. The carbonising temperature is 500°C. The volatiles pass backwards through the coal, and the tar deposits its dust in filtering through the coarse-grained coal. The carbonised residue is used for pulverised-fuel firing.

23 The results so far obtained indicate that the low-temperature carbonisation of brown coal, combined with pulverised-fuel firing, when carried out at the mine, are efficient ways of utilising Korean coals. The objective is, therefore, the installation of suitable power plants on the site of all coal mines, in order to convert the fuel into electrical energy at the spot where it is mined, and to inter-connect them with transmission trunk lines, and distribute electrical energy into all the principal cities and industrial districts in the Korean peninsula.

24 The Institute of Industrial Chemistry in Bucharest has obtained satisfactory results in the distillation of Roumanian lignites at low temperatures. The primary coke from this process is briquetted, the binder containing 97 per cent. of lignite tar and 3 per cent. of oil tar (A10).

25 Experimental work on the low-temperature carbonisation of lignite is recorded also in paper A6. In this case, the lignite char produced was briquetted with sulphite liquor, and the briquettes rendered waterproof by a second carbonisation, in order to carbonise the binder in the briquettes. The experiments proved unsuccessful. High-temperature carbonisation gave better results, but in this case the industry has been suspended, as the result of the ovens becoming damaged during a strike.

26 *High-Temperature Carbonisation.* The plan generally employed, as described by Formánek (A6), consisted in carbonising lignite at high temperatures in a modified form of Appolt oven. Plants having capacities upwards of 300 tons of lignite per day have been used for a number of years. The temperatures employed reached 1,100° to 1,300°C. The carbonised residue was screened

in three sizes. The fines were briquetted with lignite tar pitch. The larger sizes were used in boiler furnaces and gas producers. The latter type of plant is more generally applied to the gasification of raw lignite.

27 *Gasification.* About 40,000 tons per annum of Bohemian lignite is gasified in producers of the Mond, Kerpely, Koller, Heller, and other types. The following extract is given as an example of the yields obtained with a low-grade lignite: "The Mond gas producer plant at the Mannesmann Works uses low-grade lignite, which has 30.5 per cent. moisture, contains 31.82 per cent. of ash, and 0.81 per cent. of nitrogen in the dry lignite, and has a heating value of about 5,400 B.Th.U. per lb. From 1 metric ton of gasified raw lignite are recovered 45,000 cu. ft. (at 0°C. and 760 mm.) of gas of 158 B.Th.U. per cu. ft., 61.4 kilos of tar, and 16.5 kilos of ammonium sulphate."

28 *Briquetting.* The briquetting of raw lignite has been practised for many years. Formánek gives details of the practice in Czechoslovakia. Briquettes are made without a binder; the pressure employed in the moulding machines reaching from 1,300 to 2,000 atmospheres, and plants have capacities up to 600 tons per day. Some of the lignite beds exhibit more plasticity than others, hence, mixing is adopted in some cases. About 200,000 tons of briquettes are made annually in Czechoslovakia.

29 *Conclusion.* There appears to be a unanimous desire on the part of several authors that a standard system of coal classification be formulated.

The papers contain valuable information relating to large-scale experimental work on the utilisation of low-grade fuels, and record substantial progress towards a solution of the difficult problems of the combustion and distillation of lignitic coals, vast reserves of which await exploitation.

DISCUSSION

TUESDAY, SEPTEMBER 25 (MORNING)

Section A

THE COAL INDUSTRY
ECONOMIC AND GENERAL CONSIDERATIONS

Chairman—THE RT. HON. LORD ABERCONWAY (Great Britain)

THE CHAIRMAN in opening the meeting said that as an Englishman addressing so many friends from other countries, he was deeply interested in the production of coal and recognised how important it was to organise that great industry, not only from the technical but from the commercial point of view. In England we had no organisation in the coal industry. In Germany, on the other hand, the home of organisation, we found the coal trade in a position of comparative security, with regulation of output and prices and with associations able to deal with the mine owners and coal producers in other countries. We had nothing of the kind in Great Britain, though we were the oldest coal-producing country in the world and our output to-day was so far in excess of our own requirements that we depended largely on exporting coal abroad. Our system generally was bad. The coal was owned by land-owners who compelled collieries to work their coal whether at a profit or, under their mineral leases, practically a loss. We have spent large sums in equipping first-class collieries and, because we produced more than we could sell, we were all struggling in the market to dispose of our coal, no matter at what price. Sell we must, even at a loss, and he deplored the fact that a nation so intelligent as ours should not see the necessity for a complete sales organisation such as that to which some of those attending the Conference were pointing the way. Therefore, he welcomed the members of the Conference as helpers in this great cause. The question of classification was of the utmost importance, and if the Conference did nothing more than to establish a system of classification it would be doing excellent work.

Mr. J. Roberts, the General Reporter, then presented the General Report to the Section.

DISCUSSION

MR. WALLACE THORNEYCROFT (Great Britain), Vice-President, in opening the discussion said that it was apparent that the majority of the papers dealt with the classification of coals in various ways and it would perhaps be appropriate for him to refer to the object aimed at in the wide-spread attempt to devise a "simple system of classification both scientific and useful." These were the concluding words of

Mr. Fieldner's comprehensive paper describing the organisation that had been set up in the United States for the purpose. Mr. Fieldner's paper indicated that the American conception of the problem postulated a thorough scientific investigation before attempting to harmonise the scientific classification with what he called the "use" classification. There would be agreement in this Conference he (the speaker) imagined, with that procedure. Before coming to more detailed questions he thought it desirable to consider for a moment the cause of this wide-spread desire for classification of coal in order to make clearer the objects to be kept in view. Before the world war in 1914, investigations of the composition of coal and the use to which the infinite varieties found in the earth could be put were chiefly confined to comparatively few experts concerned with its winning, working, distribution and consumption; and progress was slow. Since that time, either by reason of shortage of supplies or, latterly, on account of excessive supplies offered in the markets of the world, coal had been very much in the limelight, and consideration of the supply of and the demand for coal had been forced upon the Governments of nearly all civilised countries. It was not unfair to suggest that the majority of those in high places in Governmental circles in all countries were more or less astonished to find how little they knew about coal; and the general public knew less. Hence the initial demand for more information and the provision of public funds for the purpose of scientific investigations which have already materially added to our knowledge. Many new terms had been used by investigators in their description of the complex component parts of coal, and there was evident necessity for scientific definition of the terms used and even for the methods used for the separation of the substance referred to, in order to arrive at a scientific classification of coal. Increase of knowledge leading up to this would be welcomed by all.

Whether scientific classification could be used in commercial practice had still to be determined, and involved definition of commercial practice. It would not be disputed that before the war the commercial value of all classes of coal was adjusted by the free play of competition between producers, and that each consumer was supplied with the available variety best suited to his purpose as the result of the accumulated practical experience of producers, distributors and consumers. The classification for commercial purposes was, therefore, automatic and extremely delicate but dependent upon competition. Again, it would not be disputed that the producer whose costs permitted the delivery of a suitable variety of coal to the place of consumption at the lowest price would command that market. It was difficult to see how any specification or classification of that variety would alter this; but subsidies to lower cost of production or distribution certainly did have such a result. The present supply of coal was greatly in excess of the demand. The desire of each producing area to get the maximum possible share of the trade available might account for the suggestions of commercial classification. It was not the object of the

Conference to discuss the subjects of free competition between producers, subsidies to lower costs of production or distribution, etc., but these and other essentially commercial matters must be considered before deciding whether any commercial classification based upon a scientific classification was desirable, possible and equitable.

Coming to the scientific classification of coal, Mr. Thorneycroft said that Dr. Wheeler's paper opened up a wide field for discussion and showed the necessity of going back to the processes involved in the formation of coal when considering classification. In his opinion bacterial action was most important, and he commended a study of the papers by Kidston and Lang on the peat-like deposits found in the Devonian Rocks near Elgin in Scotland, published by the Royal Society, Edinburgh. The original plants could not be neglected, and some change in the variety of plants flourishing during the accumulation of the coal forming materials might account for the fact that entirely different classes of coal were often found in this country in the same seam; and usually seams lying one above the other but separated by a few fathoms of shale or sandstone were of different classes, although they must have been subject to the same geological conditions after the formation of the original mass of vegetable material. Several papers referred to similar characteristics of coal of the same geological age subject to alterations due to observed earth movements and volcanic action.

As the primary function of coal in practical use was to generate heat, superficial consideration would point to classification by its calorific value only as measured by a calorimeter or calculated from the ultimate chemical analysis; but it would probably be agreed that this only touched the fringe of the question. It would be interesting to hear the views of the Conference on the suggestion from Austria that the reference figures prepared by them "approach as near as possible to the ideal average of pure coal values." In all this intensive scientific study of the characteristics of various coals the samples worked upon were presumably drawn from particular seams, but when we came to commercial classification it must be remembered that we had to deal frequently with mixtures or blends of various seams and the vexed question of sampling as well as the method of analysis must be considered. The standard specification issued by the Netherlands for sampling and analysis would come up for discussion.

The resources of what were called low rank coals were dealt with by several authors, and it was evident that these had been brought into prominence by political considerations which were outside the limits of discussion at the Conference. Their use and treatment depended upon and varied with the amount of water and ash that they contained. Most of the papers referred to whole seams of coal, but it was perhaps worthy of mention that some low rank coals were found as parts of seams of much higher quality.

Treatment of these low rank coals by high temperature as well as by low temperature carbonisation was described at length, as well

as briquetting; and discussion would probably emphasise the fact that each particular coal required a special study and that it was not safe to say that any particular form of apparatus, successful, with one coal, would certainly be satisfactory with another.

Consul-General E. G. SAHLIN (Sweden), speaking with regard to the classification of coals, said that this matter had been gone into in Sweden to a considerable extent, with the result that some of the larger consumers there now bought coal under a guarantee with regard to heat value, ash content and moisture. The average value, however, depended not only upon these three factors but upon other properties such as the origin of the coal, its coking and slack forming tendencies, its volatile contents and so on, all of which had a great influence upon the amount of heat which could be obtained in practical use. The useful heat, however, was the factor of primary importance to the consumer. It was well known that a high percentage of dust and small coal resulted in considerable losses owing to the small particles falling down through the stoker without being consumed. It was also well known that the percentage of volatile substance had a great influence on the commercial results obtained, and where a high furnace temperature was demanded, and particularly where the air was pre-heated, it was almost impossible to use a coal with a low fusing temperature of the ash. Under these circumstances it was only reasonable that the user should demand reliable information in advance with regard to the properties of the coal. For instance, the expression "large steam coal" was much too vague and formed a quite insufficient basis upon which to judge the properties of a coal. Very often coal delivered as large steam coal contained from 30 to 40 per cent. of small coal, which resulted in the quality varying a great deal. This lack of international accord in terms of definition left very much to be desired, and the Swedish Delegation placed before the Conference the following resolution:—

> "Whereas it appears desirable that an international nomenclature for the classification of coal with regard to its properties be adopted and that a uniform system for the determination of the fundamental properties of coal be established: *Resolved* that the International Executive Committee of the World Power Conference be requested to take suitable steps to that end."

THE CHAIRMAN remarked that the resolution had been accepted by the Executive and asked if anybody desired to discuss it.

MR. C. LE MAISTRE (Great Britain) said that this was a question not only of scientific but of great commercial importance and a resolution of this nature should be regarded with the very greatest caution. A considerable amount of work had been done in America on this subject and it was well known in this country that a great deal of work was also in hand. Therefore, if the World Power Conference was to set up any organisation or machinery to attempt international standardisation at the present moment, it would be not only not progressive but harmful to the delicate discussions going

on at the present time. Therefore, he wished seriously to strike a note of warning, and to suggest that such a resolution should not go forward without very careful consideration and that at the moment the World Power Conference should not set up any international machinery until the various countries interested had had time to put their own house in order. No doubt the discussion would be sufficient to ventilate the subject as it should be ventilated, but the problem was so wide-spread, the difficulties so tremendous, and the commercial considerations so delicate, that each country should be allowed considerable time to put their own house in order before any attempt whatsoever was made towards international agreement.

Dr. E. W. Smith (Joint Technical Secretary) speaking on behalf of the Technical Committee of the Conference, said there was not the slightest intention of recommending the World Power Conference as such to carry out any of this work. The object of the resolution was merely to empower the International Executive to see that it was done. At the moment there was no organisation in existence which had the duty of inaugurating co-ordination of this kind. He reminded Mr. Le Maistre that the Conference was definitely representative of the very organisation on behalf of which he was speaking, and the suggestion was that this Conference be empowered to take a watching brief to see that everything was done on behalf of the British Engineering Standard Association and of other international bodies to co-ordinate their work. There was no intention of the Conference carrying out the work itself.

Dr. A. Parker (Great Britain) said that while it was perfectly clear that differences in many respects would be necessary in consequence of the different conditions in various countries, there were, nevertheless, certain methods which might well be standardised. At the meeting in the afternoon of Section B the question of sampling and testing solid fuels would be discussed, and, perhaps, some of the methods would be dealt with in greater detail. As a result some scheme for arranging co-operation between the different committees of different countries might be devised and he supported the resolution.

The resolution was then put to the meeting and declared carried.

Mr. F. C. Faraker (Australia) said that it had been hoped to have presented to the Conference a comprehensive report on the coal resources of Australia. Unfortunately the report had been received too late and was, in fact, still in an unfinished form. It would, however, be placed at the disposal of the Conference later.

Mr. H. Laffer Lewis (Australia) thought he was right in saying that the State of Victoria had already proved more brown coal than that which had been found in Germany, which was the home of brown coal development. The depths of many seams of brown coal in Victoria were unusually thick. There were several bores showing between 400 and 500 ft. of coal in the neighbourhood of Yallourn, whilst at Morwell there was almost 800 ft. of coal showing, whilst the bore was only just over 1,000 ft. and at the time of ceasing boring operations they were still in coal.

The Yallourn coal was very similar to that of the middle German brown coal, being friable and having a water content of approximately 64 per cent. and a gross calorific value of a dry sample being approximately 10,850 B.Th.U., the ash content being extremely low and slightly over 2 per cent., which was a very important factor.

The main power station at Yallourn had a capacity of 75,000 kW., and at present was being extended to 150,000 kW., the whole of which was operated with Yallourn brown coal having a moisture content of 64 per cent. Considerable trouble was experienced in the initial stages of starting up the plant in the burning of this high moisture content coal on the underfeed travelling type of grate which was selected. To increase the evaporative capacity of the boilers pre-drying shafts of the louvred type were installed in some of the boiler units. This resulted in considerable drying effect on the coal, but led to excessive draught drop, and difficulties were also encountered from the coal sticking in the drying shaft.

These louvred dryers were subsequently superseded and fixed step grates were tried in front of the underfeed mechanical travelling grate. The results obtained in this direction were encouraging, and several boiler units were equipped with this type of furnace. Some of the step grates were mechanically operated. Stationary step grates were used at the Commission's briquette factory and were adopted after experience gained in Germany. Such information was not obtainable at the time the power station was designed, for this followed immediately after the end of the late war, at which time negotiations with Germany were difficult. The step grates at the briquette factory had been most successful and had resulted in boiler evaporations considerably in excess of the guarantees of the manufacturers. Some of the latest boilers at the power station had been equipped with mechanical step grates using pre-heated air with great success. There was no doubt that mechanical step grates with pre-heated air were most suitable for brown coal power stations having to meet large fluctuations in steam demand. Auxiliary dust-firing might be used to great advantage to overcome these peak loads which had to be met at short notice. The briquetting plant of the Commission was designed along similar lines to that used in Germany and was installed in 1924. The average output of the present plant was 400 tons per day and was at the present time being extended to give an output of approximately 1,250 tons per day. For the purpose of general economy, etc., it was decided in these extensions to the briquette factory to adopt a steam pressure of 650 lb. and 750°F. This would be the first high-pressure plant in Australia and was being watched with considerable interest by all engineers out there. For the purpose of studying high-pressure power station development, the speaker had made a world tour last year on behalf of the Commission, and he was greatly impressed with the extent of high-pressure power station development, particularly in the U.S.A. and Germany. He had, during this tour, visited every high-pressure plant of importance in the world, with the exception of South America. The Commission had

made considerable investigations into the pulverising of brown coal with very satisfactory results, but the cost on a B.Th.U. basis was not favourable, at least for the present, in comparison with the cost of black coal in Victoria. The results of the Commission's investigations had been published in a bulletin which was now available. The Commission had also investigated the recovery of by-products and the carbonisation of brown coal, but the prospects of such a plant on a commercial basis were not hopeful at this stage, with the high cost of labour and plant in Australia. The findings of this research work had also been published in a bulletin by the Commission. Considerable development had taken place in Germany during the last few years in carbonisation and the recovery of by-products from brown coal, which were being watched with very great interest by engineers all over the world. The economic conditions, however, in Germany were very different to those existing in Australia. The developments of the Victorian brown coal field were in its early stages and there was no doubt that there was a very large future in front of this State in the development of its natural brown coal resources. The Yallourn brown coal was supplied to the boiler bunkers for 2s. per ton. Although only having a heating value of approximately one-third of good black coal, it was very much cheaper than the latter which cost from 36s. to 40s. per ton for large consignments.

Mr. William J. Erdös (Hungary) discussing new types of mechanical stokers, said that on the basis of experiences in the countries which use low grade as well as high grade fuels, it could be stated that the mechanical stokers play a significant and ever-developing rôle in connection with energy and steam production. Three kinds of mechanical stokers were known in general: (1) Wandering stokers; (2) Underfeed stokers; (3) Forefeed stokers.

The first two were most suitable for high-grade fuels, because when using inferior fuels, especially those containing a great quantity of ash, notably when of low smelting temperature, many difficulties arose. For instance, the fuel and the ash smelts and bakes on the whole width of the grate-surface and the clinkers included much unburnt fuel; and, further, in consequence of the inpenetrability of the ash clinkers, the air distribution and the combustion became uneven.

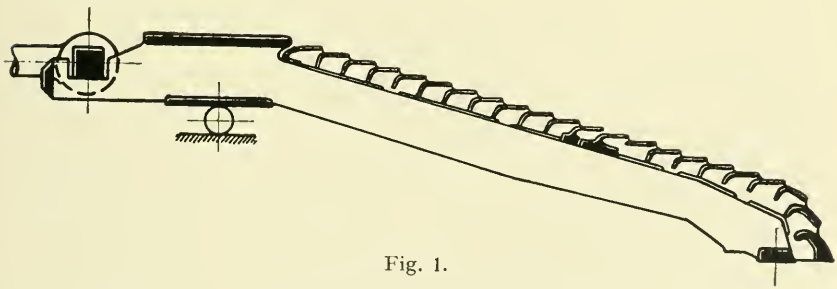


Fig. 1.

Bar Bearers and Record Bars.

In certain parts of the Danube basin, for example in Hungary, there were different kinds of coal with an ash content up to 30 per cent. and more. The following table showed the varieties of Hungarian coals, according to their geological age and content of calories and ash:—

Geological age	Occurrence	Variety	Calorie W.E.	Ash per cent.
Lias and chalk	Pecs Manyok Komlo	coal	4,000-6,500	15-35
Eocen-Oligocen	Tata Dorog	brown coal	4,000-5,600	7-20
Lower Mediterranean	Basin of Salgotarjan	brown coal	3,500-5,000	14-35
Upper Mediterranean	Basin of Borsod	brown coal	2,200-3,600	12-35
Pontus-Pannonia (lignite)	Varpalota Gyongyos	lignite	about 2,000	12-25

The problem of constructing a stoker, able to burn economically and with a high capacity both the superior and inferior kinds of coal and dust and waste, had been taken in hand in Hungary, and the Record Stoker which had been in use for two years at the Budapest Royal Polytechnical University in practical experimental work with various fuels, produced the most favourable results. The construction consisted of alternatively forward and backward moving long bar bearers, which bear the record-bars of a special form (Fig. 1). These were a combination of a relatively high barstem with a series of wings, each having an upper shank and a lower shank partly overlapped by the upper shank of the adjacent wing. The top surface of each upper shank was slightly inclined. This structure prevented, on the one hand, the falling of dust and small coal, while, on the other hand, it ensured a favourable distribution of air and a very efficient cooling of the material, and therefore a great durability in fire. That was important with regard to the recently increased application of air pre-heating and also to the large grate-capacity and high grate temperatures, which required fireproof grates. On these points favourable working results had been obtained.

With the collaboration of the Calory Economical Section of the Budapest Royal Technical University, under the direction of Prof. Schimanok, experiments had been made on Record Stokers with different kinds of coals from 2,500-6,500 W.E. calories, in course of which a grate capacity of 1,000,000 W. E. calories was obtained. If a larger specific grate capacity were desired it could be attained by the extension of the fire space. In this case, fore furnaces without irradiation to the boiler were used, and the capacity of the fire space reached 690,000 W.E. calories per cu. metre and the temperature over the grates 1,400°C. Under these conditions fire bricks

of Seger Kegel 35 had been damaged, but the fire bars of the Record Stoker showed no sign of wear and tear after being in use for two years.

An improvement on the original construction was an adjustable rocker dump. The inclined angle of this dump could be adjusted

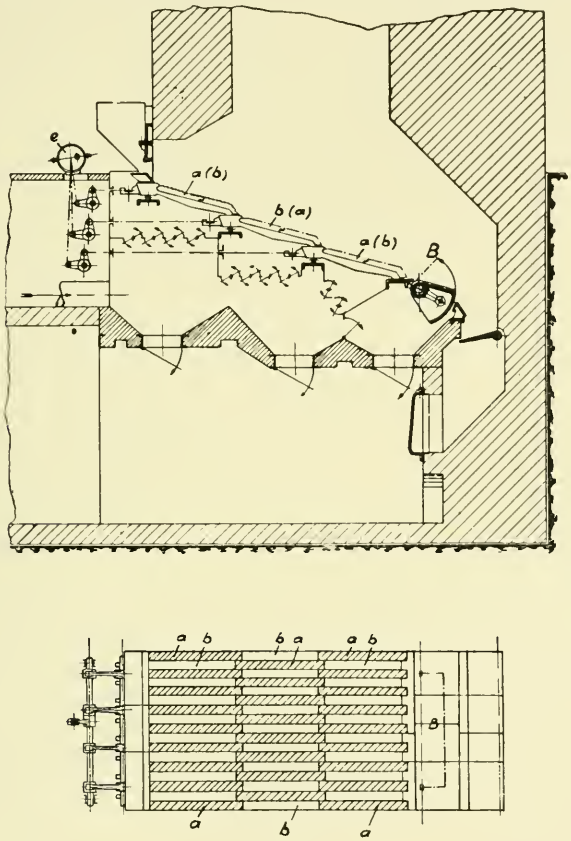


Fig. 2.
Record Stoker of high burning capacity.

to the grate end. This gave, when working, a very quick adaptability to the different combustibles and loads. The length and number of strokes could be adjusted as required. The bar bearers worked on rollers whereby a noiseless and frictionless working was ensured. The Record Stoker had been developed to make it adaptable to the largest grate surfaces (Fig. 2). In this case the bar bearers were arranged in three or more groups. Every group was driven from the same main axle, but with a separate excenter and lever transmission, so that the stroke length of the bar bearers could be separately adjusted in every group in a few seconds with

a hand wheel. The height of the bed of combustible could also be adjusted according to need. The air conducted in the ash pit of each grate group could also be regulated. The moving bar bearers A and the fixed bar bearers B were placed alternately after the manner of squares on a chessboard, and thus a very efficient agitation and crushing of the combustible and ash in several directions was ensured. On the two side walls of the Record Grates were hollow cast-iron blocks, cooled by air, which, on the one hand, prevented the baking of clinkers into the fire-bricks and, on the other hand, pre-heated the primary air for the burning. Over rolling of the fuel was by this structure impossible, because the incline angle was not too great; against this, the combustible and ash wandered with the desired layer height and speed towards the end. The idea in this grate was to create a fore feed stoker adaptable to any kind of fuel, at the same time, meeting all other requirements in connection with a mechanical stoker of high capacity and efficiency.

Prof. L. K. Ramzin (U.S.S.R.), referring to the paper presented by the State Electricity Commission of Victoria on the subject of the combustion of Victorian brown coal, said the results and conclusions corresponded in the main with those achieved in Russia, although the work of Australian and Russian engineers had been carried out independently. Among the fuels containing a high percentage of moisture used in the U.S.S.R. for burning on chain grates, were peat, tan bark, wooden chips and brown coal. It was known that the more volatile matter the combustible contains, the more difficult it was to attain steadiness of the combustion process. With fuel containing the same percentage of moisture and with other conditions equal, when the content of volatile matter was increased, the temperature of a fuel bed was decreased. Therefore, the combustion of wood and peat containing 70-85 per cent. of volatile matter, as compared with Australian coals containing 55 per cent. of volatile matter, presented greater difficulties. Nevertheless, Russian engineers had succeeded in achieving good results with complete steadiness of combustion on chain grates with wood containing 45 per cent. moisture, and peat containing up to 62 per cent. moisture, a heat liberation of 1,000,000 calories per square metre of grate per hour recorded, and this figure corresponded with Australian practice.

The following conditions were essential for correct combustion of fuel containing a high percentage of moisture; (1) The increased covering of the grate by arches, in order to prevent cooling of the fuel on account of radiation. The best results were attained with long back arches. As regards the arch arrangement Russian constructions were similar to those of the Australian, and he considered them to be quite correct. (2) Application of hot blast. (3) For fuels with very high moisture content it was essential to pre-dry the fuel in the combustion chambers by means of a special apparatus. In the U.S.S.R. this consisted of a shaft, but not an inclined grate. It had been found that a drying shaft was cheaper and more convenient in use. One of the Russian constructions of grates with

the shaft dryer was described in the paper No. *R*6. Another construction was, in the main, similar to that illustrated in Fig. 10 of the Australian paper.

A stationary grate of step grate type could be used only for fuels containing a very small percentage of ash, for instance, for Australian lignites which contained only 2 to 4 per cent. of ash. Russian experience in connection with the use of such grates of German type for brown coal (sub-Moscow coal), containing a high percentage of ash, showed very poor results, because these grates require a considerable amount of manual labour for cleaning the steps from ash. (4) As regards pre-drying of coal outside the combustion chamber, the decision of the State Electricity Commission of Victoria to dispense with the pre-drying was quite correct. Pre-drying, of course, improved the process of combustion and decreased losses with flue gases, but at the same time the heat consumption was bigger, as additional heat was necessary for the dryer and there were considerable losses in the dryer with escaping dust. Russian experience showed that the loss of brown coal when drying in the ordinary type of gas drum dryer with normal cyclones amounted to 5 to 10 per cent. Therefore, if the efficiency of the installation was to be calculated, taking into consideration not the dried coal but the raw coal supplied into the dryer, the efficiency of the installation equipped with a pre-dryer would be less as compared with the installation with direct firing of raw coal. Further, pre-drying made the installation more complicated and increased the cost of it.

As far as the Australian engineers had succeeded in solving the difficult problem of direct combustion of coal containing a high percentage of moisture, the pre-drying ought to be abandoned, because pre-drying would reduce the thermal efficiency of the installation and in any case would increase the cost of a ton of steam.

Finally, because the Australian brown coal had a low content of ash and large content of volatile matter and moisture, it was necessary to abandon the idea of burning this coal in a pulverised state until the method of pulverising such coals without preliminary drying was improved. Indeed, the application of a pulverised fuel system to brown coal combustion as compared with mechanical stokers could only give a negligible increase of boiler efficiency, and this advantage would be eliminated entirely owing to the consumption of fuel, and losses during the drying process. The cost with a pulverised fuel system would also be considerably higher on account of the necessity to have a cumbersome and expensive drying plant. Therefore, in his opinion, the State Electricity Commission of Victoria had worked out a correct and economical method for burning brown coal and had solved a very difficult technical problem. Good results could be achieved by providing the chain grates with hot blast and pre-dryers of a shaft type, as illustrated in Fig. 10 of the Australian paper.

The pre-drying could be intensified by sucking hot flue gases through a bed in the upper part of the shaft, *i.e.*, leading the gases through in the direction opposite to that of air. Such a method

had been applied successfully in connection with burning tan bark, containing a high percentage of moisture. As a general conclusion it appeared to him that the technique of combustion had made such progress that it was now possible to burn any type of low grade fuel efficiently.

With regard to the paper presented by Prof. Kamo on the question of combustion of pulverised Korean anthracite; as was pointed out in his own paper, *M7*, on combustion of pulverised anthracite culm, the problem of the combustion of anthracite even with a high content of ash could be considered as solved. Russian anthracites had an average of 5 per cent. and a minimum of about 3 per cent. of volatile matter in combustible matter, *i.e.*, less than Korean anthracites, which gave during the tests 7 to 10 per cent. of volatile matter. Moreover, there had been no difficulties in maintaining the steadiness of combustion with Russian anthracites. The softening point of ash of Russian anthracites was considerably less than that of Korean, and varied from 900 to 1,250°C. The average softening point was about 1,180°C. as compared with 1,300°C for Koreans. Nevertheless, with a furnace of rational construction even without water cooled walls, Russian engineers had had no special difficulties with slag and its removal. The use of water-cooled walls was desirable, but their surface must not be increased too much in order to avoid any troubles with ignition, and the correct combustion of the anthracite. The application of water-cooled walls ought to be accompanied by hot blast from air pre-heaters. Furthermore, with the unit type of pulveriser "Aero," used in Korea, there was no necessity to dry anthracite down to 1 per cent. of moisture. In the Moscow Thermo-Technical Institute they always burned raw anthracite culm containing about 8·5 per cent. of moisture and sometimes as much as 14 per cent. without pre-drying but supplying the Atritor mill, manufactured by Messrs. Alfred Herbert & Co., with pre-heated air at the temperature of 150 to 250°C. The elimination of a dryer simplified the plant and increased its efficiency. The fineness of grinding, according to his experimental tests, was sufficient when the remainder on a standard American 200 sieve varied from 12 to 15 per cent. High-speed centrifugal mills were not suitable owing to their rapid wear and tear. Finally, the efficiency of the furnace was about 88 per cent. as compared with 74 to 82 per cent. of the Korean plant ($T—t=150$°C.).

Many of the papers contained suggestions as to the desirability of adopting international standards in power engineering. This showed once more that the time had now come to emphasise the necessity of forming a special International Standards Committee of the World Power Conference. The Russian Delegation had laid a proposal before the International Executive Council, and he wished to emphasise once more the importance of this question, and to ask the World Power Conference to take the initiative in connection with preparing international standard specifications relating to all the main branches of power engineering. The increased scientific and industrial co-operation of different countries demanded

standardisation, unification and normalisation, and he hoped that the resolution which would be proposed by this section would be supported.

Dr. Tomaides (Austria), speaking in German, suggested that international standards should only be agreed upon after each country had prepared a full list of all its available coals and the nature of those coals, which information should be sent to the Central Office of the World Power Conference. But it was first necessary, in order that comparison might be possible, that international standards should be agreed upon for coal.

Mr. Clarence A. Seyler (Great Britain) said that the paper by Prof. Stansfield illustrated the urgent need for some uniform system of classification, and raised many interesting questions, among them the meaning of the term "the rank" of a coal. In a general way we knew that this meant the degree of alteration of the original plant material; but how was this to be measured? It would be seen from Prof. Wheeler's paper how little agreement there was as to the causes and nature of this metamorphosis. The United States Geological Survey favoured a system based upon the volatile matter and certain physical properties, such as the tendency to disintegrate or slack, which were difficult to measure. Others suggested the amount of hygroscopic water, or the sum of this and the volatile matter. Careful examination of the coals of any region where we might assume progressive metamorphism in a definite direction, would throw light upon the problem. Such a case was that of the coals of South Alberta, discussed by Prof. Stansfield. Here the volatile matter or fuel ratio based upon it did not show as good a progression as the moisture. Unfortunately, the elementary composition was not given. There was no doubt that the amount of hygroscopic moisture was closely related to the rank of a fuel, especially if it could be made definite by exposure to air of a constant humidity, as was the practice of Prof. Stansfield. He would like to suggest, however, that the moisture should not be expressed as a percentage of the raw coal but as a percentage of the pure coal or organic material. Prof. Wheeler had admirably discussed the inferences which might be drawn from the graphic treatment of the analytical data of coal by himself (the speaker), Ralston, Hickling and Parr. On a carbon hydrogen chart, coal formed a narrow band which showed the progress of alteration of rank. On such a diagram the volatile matter, calorific value, hygroscopic moisture and practically every property of coal could be expressed by lines more or less regularly disposed, such as the isovols and isocals. Any property which varied continuously throughout the series, without serious overlapping from one class to another, would evidently be a good measure of rank. Such a feature appeared to him to be the amount of carbon. The carbon axis cut the coal band nearly at right angles to its direction over the whole series as far as the semi-bituminous species. For coals of higher rank the hydrogen became more important. Prof. Ramzin had raised the objection of isomerism to all classifications based on elementary analysis and gave the

instance of the composition of sapromixite. The answer was that the classification applied only to *coal*, which was a rock of persistent physical and microscopic character. Sapromixite, he (the speaker) suggested, had not these characters and was, therefore, not coal. Further, the classification which he himself had suggested did not ignore the volatile matter and caking properties of coal. It was, indeed, based upon the graphical proof of a close connection between these properties and the elementary composition. If sapromixite with 90 per cent. of volatile matter were placed on the diagram, one would conclude, rightly, that it was not a coal. Time did not permit of adequate discussion on Prof. Wheeler's suggestions for a rational analysis of coal. The general lines of these suggestions, however, were sound, based as they were upon botanical considerations derived from microscopic study. Prof. Wheeler's work in conjunction with Dr. Francis on the regeneration of the ulmins by oxidation was one of the most important steps in coal chemistry which had been made during recent years. Concerning Mr. Fieldner's paper, he would say no more than that, by the courtesy of his American friends, he had been able to collaborate with them in the very important work of trying to agree upon a uniform system of classification which was at present an urgent need, not only of the investigator but of the technical man, consumer and producer. He had been very struck by the fundamental agreement between his own classification, which was made in 1900, and the latest classification devised by Prof. Parr in America. Considering that they started from very different angles the agreement was rather astonishing and seemed to him a hopeful augury for the possibility of securing a uniform classification. It was to be hoped that other nations would take part in the discussion of this question, so that we might arrive at a real world-wide classification.

Sir Albert Kitson (Gold Coast), speaking with regard to the combustion and drying of coal, asked Mr. Lewis whether there was much difference in the character of the air-drying of the Yallourn and the Morwell brown coals. In Victoria, Australia, there was undoubtedly the largest known deposit of brown coal in the world. Not very many years ago he was associated with the Victorian Geological Survey and knew the Morwell brown coal deposits, which were proved by the Maryvale bore to have beds aggregating 808 ft. in thickness in the total depth bored of 1,112 ft. That represented an enormous amount of coal of much greater value even than the great deposits of Germany, where there were deposits of over 300 ft. thick, for instance those at Ichendorf, near Cologne. There were also large deposits in Bohemia and in Southern Nigeria, but those could not be discussed at the moment. What he wished to point out was that the Victorian brown coal deposits were a most valuable asset, and it was specially pleasing to know that they were being energetically developed for the production of electricity. There were other important deposits in Victoria, such as that at Altona, within 10 miles of Melbourne, where the bed had been proved to be 75 ft. in thickness, under a cap of basalt. This brown

coal bed extended westward across the Melbourne-Geelong railway, and eastward under Port Phillip. It promised to be a great asset in the future. Having examined the deposits at Ichendorf and near Halle, Germany, and seen other deposits in Bohemia, as well as those in Victoria, he was of the opinion that neither of the German coals mentioned was as good in quality as those of Morwell and Altona. In the Ichendorf deposits the coal contained a considerable amount of wood (remnants of trees), so that it had to be treated before it could be briquetted. In these Victorian beds, on the other hand, the coal was homogeneous, a true brown coal, not a lignite. It was essential to recognise clearly the distinction between the two kinds. In Cologne he had seen a train of forty trucks, loaded with brown coal, drawn at a good speed by a locomotive using only brown coal as fuel. This was another example of the value of brown coal and the great asset the brown coals of Victoria would be when they were fully developed.

Prof. Kamo (Japan), speaking with regard to pulverised fuel, said that whilst anthracite with 5 or 6 per cent. moisture could be pulverised without drying, he doubted whether it was possible to burn it without any kindling mixture, however finely it be pulverised. It had been found from experiments in the Fuel Research Laboratory at Korea that anthracite coal containing only 3 to 4 per cent. volatile matter could be burned quite successfully when pulverised, if it were dried until the moisture contained was less than 1 per cent. With regard to semi-coke, a fact had been established since he had prepared his paper which might already be known, but it was new to him. Burning Korean brown coal into a semi-coke by low temperature carbonisation gave a product representing 55 per cent. or 60 per cent. of the original raw coal, and the calorific value of that semi-coke was 25 per cent. higher, on the average, than that of the raw coal, and when it was used as a boiler fuel the evaporative capacity of this semi-coke was 40 to 50 per cent. higher that that of pulverised raw coal. It was, therefore, believed that the installation of low temperature carbonisation plant for this purpose would justify itself economically. The estimate of capital cost was £400 to £450 per ton capacity of coal carbonised per day. Low temperature tar could produce a net income of about £2 10s. per ton in Korea and there was a 10 per cent. tar yield from the coal. Therefore, he suggested that the best way to utilise that particular brown coal was to carbonise it first and use the semi-coke in a pulverised condition for the generation of power.

Mr. Wallace Thorneycroft (Great Britain), Vice-President, speaking on the question of classification from the commercial point of view, said it seemed to him that the representative from Sweden had neglected the fact that recognised brands of coal were exported not only from this country but from Germany and elsewhere to Sweden, and the users of these named brands had got to know a good deal about their characteristics. That was a form of classification that had been in practice for a large number of years, and when a quotation was given for a known brand it was recognised as having certain

properties which, however, might vary from time to time, although only to a very small extent. What was wanted, however, was a perfectly clear classification of the terms used in analysis and in the description of coals in order to avoid, as the Marquess of Reading had stated at the Banquet, people wasting a good deal of time arguing about certain matters only to find at the end that they were speaking about the same thing but using different terms.

Mr. H. Van Hettinga Tromp (Dutch East Indies), referring to the classification of coals, said that the term "bituminous coal" was at present used to cover a large number of varieties, which really contained only a very small percentage of bitumen, whereas varieties, as for example brown coal or lignite, which contained *much more* bitumen, were called sub-bituminous coal. It would be much more satisfactory, therefore, to grade bituminous coal into classes according to its gas content, caking power, brightness, etc., as was already done in many European countries. When he was Manager of the Pelembang (South Sumatra) coal mines, he found he had to deal with a very large number of coals, all of which had originally been ordinary brown coal, but which had been transformed by the heat-action of intrusive igneous rock into all the different grades of bituminous coal, into anthracite and even coke, so there was perhaps no place on earth where on one spot the different characteristics of coals could have been studied better, and it was from his experience there that he had come to the conclusion that we are still a long way from having a *rational* classification of coals. In the same way the general use of the word "ulmin" was misleading, because "ulmin" covered different kinds of constituents of the coal, all derived from the "lignine" substance of the original vegetable matter. It was preferable, therefore, to use the words "lignine compounds." Anybody interested in this matter was recommended by the speaker to study the work by M. L. Crussard in the "Revue de l'Industrie Minerale" of 1926 and 1927.

In the "use" classification, the term "smithy" coal was used, but that was only good for the metallurgical industry, whilst "good steam coal" was equally applicable to railway coal, etc.; for these reasons, he thought the system put forward by the American Committee was not logical. These anomalies demonstrated the need for some such action as that contemplated by the resolution which had been passed.

A cordial vote of thanks was passed to the Chairman, Vice-Chairman, authors of papers and speakers in the discussion.

The following written communications are appended:—

Mr. Wilfred Boyes (Great Britain)

Classification of Coals

As an ordinary member of the Conference who has closely followed the discussion of the session dealing with the above, I should like, if I may, to emphasise the plea to which reference was briefly made, namely:—"That whatever may be done in this direction (and we

sincerely hope that something tangible may be achieved), such standardisation or classification, whether national or international, should not err too greatly on the technical side, but should be expressed in terms which are capable of comprehension by the reasonably efficient and interested commercial mind."

The fact must not be overlooked that the actual selling and buying (for the economical operation of which such classification is being proposed), rests with the commercial departments, and any abstruse technical basis which might be agreed upon would make "confusion worse confounded."

In the selling of coal there is no doubt that colliery companies are very much behind in their methods compared with those of other staple trades; very few collieries can furnish reliable and authoritative analyses of the fuels they are offering, and it is being left to the more up-to-date and progressive merchants to take a lead in that direction.

Having some experience in assisting the buyer of a large industrial concern, possessing many works spread over a wide area in the North of England, I know how complex a job it is when fixing period contracts to make an efficient selection of coals most suitable and economical to the respective boiler plants. He may be guided very fully by the plant engineers as to the most suitable *types* of coal, and he may have at his disposal many results of tests carried out both in the laboratory and on special test boilers, but he has also to consider tenders for many other coals about which little, if any, information is available.

Such tenders may appear very attractive from a price point of view, but owing to lack of data, he does not know whether value for money would be forthcoming.

Particularly does this apply to spot lots of coal offered on the markets and which are, as a rule, subject to immediate acceptance; again, such offers often have to be declined, as the buyer does not care to take the heavy risk involved.

The buyer is also limited to a great extent to such factors as continuity of supply in reasonable quantities, also the necessity of keeping in mind the freightage and handling costs which average, at any rate in this country, a figure approximating 60 to 70 per cent. of the pit-head price of industrial coal, and he is, therefore, bound to find a source of supply as near as possible to the boiler plants.

I trust that I have not unduly laboured the point in question, but hope that it may receive the consideration which it merits, as only in this way can any system of standardisation or classification thus help to bring about the economies in coal consumption which, I think, is the greatest result hoping to be achieved by the Conference.

Lieut.-Col. F. I. Leslie Ditmas (Great Britain)

The Use of Fuel in the Netherlands

(*Paper A* 15)

In 1913 the output of coal in the Netherlands amounted to

1,842,976 tons. The extent of the Limbourg coalfield was well-known; but as the Netherlands were the dumping ground of coals from Great Britain and Germany, the price of coal was a competitive, and therefore low one. The need for developing the home industry was not apparent. Suddenly the war came, and supplies from both sources were curtailed. The Dutch as a practical people at once set about the sinking of shafts on the State and private property.

With the home production of over 8,500,000 tons per annum less coal is imported from both Great Britain and Germany. It has come as an unpleasant shock to the British miner that, notwithstanding the low price of coal, there is not the same Continental demand for it. The screening of British coal for export has made enormous progress during the past five years, and in this respect as well as in that of quoting the chemical analysis, the Dutch can no longer complain against the British coal exporter as was formerly their custom.

SECTION B

SAMPLING AND TESTING OF SOLID FUELS

B1 SAMPLING AND TESTING OF COAL.

B2 A PRACTICAL COMPARATIVE BASIS FOR THE CALORIFIC VALUE OF COAL.

B3 DETERMINATION OF VOLATILE MATTER IN COAL BY LOW TEMPERATURE METHODS.

B4 THE HYGROSCOPIC QUALITIES OF COAL.

THE NUMBERS ARE THOSE GIVEN TO EACH PAPER FOR USE AT THE FUEL CONFERENCE

PROBEENTNAHME UND UNTERSUCHUNG VON KOHLEN

(SAMPLING AND TESTING OF COAL)

GESELLSCHAFT FÜR WÄRMEWIRTSCHAFT, WIEN

*Paper No. B*1

CONTENTS

SAMPLING—SELECTION—PREPARATION—PACKING AND DESPATCH—TESTING AND ANALYSIS—RÉSUMÉ

(A) PROBEENTNAHME.—In Oesterreich haben die in der Gesellschaft für Wärmewirtschaft Wien (Arbeitsausschuss für feste Brennstoffe) über Entnahme, Behandlung und Verpackung von Kohlenproben für chemisch-technische Untersuchungen abgehaltenen Beratungen zu folgenden Festlegungen geführt:

Allgemeines.—Ein zutreffendes Urteil über eine Kohlenlieferung ist nur durch Analyse (Heizwertbestimmung u.s.w.) einer Durchschnittsprobe zu erlangen. Die Fehler, welche aus unrichtiger Probenahme entstehen können, sind viel grösser als die Ungenauigkeiten einer technischen Analyse. Eine richtig hergestellte Probe muss ein Durchschnittsmuster der ganzen Lieferung sein. Da verschieden grosse Kohlenstücke in der Regel verschiedenen Asche- und Wassergehalt haben, muss die Probe alle Korngrössen annähernd im gleichen Verhältnisse aufweisen wie die Gesamtmenge. *Die Analyse eines einzelnen Kohlenstückes ist für die Beurteilung einer Lieferung nicht massgebend.*

Die Herstellung einer richtigen Kohlenprobe umfasst folgende Vorgänge:

(1) Die Entnahme der Probe.
(2) Die Behandlung der Probe (Einengung auf die im Laboratorium gebrauchte Menge).
(3) Ihre Verpackung und Versendung.

(I.) *Entnahme der Probe.*—Am sichersten gelingt die Entnahme einer richtigen Durchschnittsprobe von einer in Bewegung befindlichen Lieferung (beim Auf- oder Abladen, Umladen).

(1) Bei Versand wird beispielsweise während des Ablassens aus der Rutsche in regelmässigen Zeitabständen mittels Schaufel so viel entnommen, dass bei einer Gesamtmenge bis 1 000 kg etwa 10 bis 20 kg, bei einer Gesamtmenge bis 10 000 kg (Eisenbahnwagen) etwa 50 kg und bei grösseren Mengen von jedem Eisenbahnwagen etwa 50 kg als Probe erhalten werden. Es sollen möglichst viele Einheiten (Schaufel, Schubkarren, Korb u.s.w.), mindestens aber deren 10 entnommen werden. Die Probe darf nicht etwa nur die grössten oder kleinsten Stücke enthalten; je ungleichmässiger die Korngrösse der Gesamtmenge, um so grösser ist im allgemeinen die erforderliche Probemenge.

(2) Ist Kohle einheitlichen Ursprunges in bewegten kleineren Einheiten verladen (Grubenwagen, Hängebahngefässe u.s.w.), so sind in regelmässigen Abständen ganze Ladungen als Probe zu entnehmen. Nur wenn die zu geringe Zahl der Einheiten es nicht erlaubt, ganze Wagenladungen zu entnehmen, soll von jeder Einheit ein Teil der Ladung entnommen werden.

(3) Aus lagernder Kohle, welche nicht abgezogen werden kann, ist je eine gleiche Gewichtsmenge so zu entnehmen, dass die Entnahmestellen gleichmässig auf der Oberfläche und im Innern des Lagers verteilt sind. Hiebei ist die Form des Haufens zu berücksichtigen; z.B. sind bei kegelförmigen Haufen aus dem Unterteil entsprechend mehr Einheiten zu entnehmen, als aus dem Oberteil. Das Schaufeln eines Schlitzes durch den ganzen Haufen und die Verwendung des so gewonnenen Materials für die Probe ergibt in diesem Falle noch den richtigsten Durchschnitt.

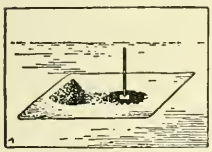
Im allgemeinen ist eine verlässliche Probeentnahme aus lagerndem Material sehr schwierig; es muss dabei allen jeweils in Betracht kommenden Umständen Aufmerksamkeit zugewendet werden.

Eine einwandfreie Probeentnahme aus einem geschlossenen Speicher, welcher nicht entleert werden kann, ist undurchführbar.

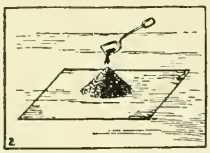
(II.) *Behandlung der Probe.*—(1) Die für den Versand bestimmte Probemenge soll für chemische Untersuchungen mindestens 3 kg betragen, bei technisch-industriellen Proben (Verschwelung) sind, je nach dem anzuwendenden Verfahren, grössere Mengen, auch bis zu 100 kg, notwendig.

(2) Die Einengung der Menge, welche nach einer der im Abschnitt I erwähnten Arten gewonnen wurde, auf die für den Versand bestimmte Menge geschieht am besten nach dem Diagonalverfahren. Man schüttet die Probe auf einen ebenen, reinen Boden, schaufelt die Kohle durcheinander, zerkleinert die grossen Stücke und bildet eine gleichmässige Schicht. Sodann zerteilt man mittels eines

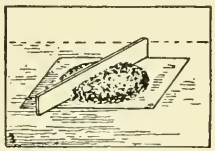
Brettes den Haufen in vier annähernd gleiche Teile, deren Trennungslinien aufeinander senkrecht stehen und entfernt von den so erhaltenen vier Teilen zwei gegenüberliegende Teile. Die übrigbleibende Kohle wird nach weiterer Zerkleinerung neuerlich durcheinandergeschaufelt und noch einmal in Form eines Haufens gebracht, welcher wieder in gleicher Weise geteilt wird. Dieser Vorgang wird solange fortgesetzt, bis die für den Versand bestimmte Menge übrigbleibt. Das Material ist auch während dieser Behandlung so weit zu zerkleinern, dass die Teilung der Haufen keine Schwierigkeiten macht.



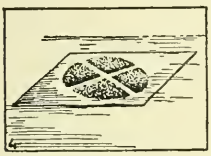
Zerkleinern des Probematerials.



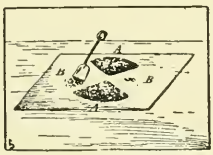
Durcheinanderschaufeln.



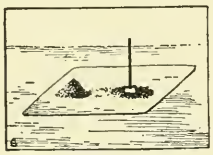
Ausbreiten und Teilen.



Beendete Vierteilung.



Entfernen zweier gegenüberliegender Teile.



Neuerliches Zerkleinern (Wiederholung von 1—5).

(3) Die Entnahme der Probe und ihre Einengung soll mit Rücksicht auf den sich ändernden Feuchtigkeitsgehalt der Kohle so rasch als möglich durchgeführt werden. Eine Unterbrechung der Arbeit und etwaiges Liegenlassen der Kohle ist nicht zulässig.

Bei Sonderproben für Feuchtigkeitbestimmung ist noch vor der Einengung der entnommenen Probemenge ein Teil derselben von möglichst durchschnittlicher Beschaffenheit in ein besonderes, dichtes Gefäss zu verschliessen. Zur sonstigen Beurteilung der Kohle ist ausser der eigentlichen Probe noch die Einsendung einiger ganzer, getrennt verpackter Kohlenstücke wünschenswert.

(III.) *Verpackung der Probe.*—(1) In wichtigen Fällen empfiehlt es sich, die für die Analyse bestimmte Probe in drei Gleichstücken anzufertigen u.zw.:

(*a*) für das Laboratorium,

(*b*) für den Abnehmer,

(*c*) für den Lieferanten.

Die Proben sind in dichtschliessende Gefässe aus Glas oder Blech zu füllen. Holzkisten sind nur zulässig, 1. wenn die Feuchtigkeit der Kohle nicht massgebend ist, bezw. wenn eine besondere

Feuchtigkeitsprobe genommen wurde, und 2. wenn atmosphärische Einflüsse die Kohle erfahrungsgemäss nicht verändern.

Verpackung in Papier oder Karton ist in allen Fällen zu vermeiden.

(2) Die Probengefässe sind luftdicht zu verschliessen, Blechdosen sind zu verlöten; auch sogenannte Klemmdeckeldosen sind gut verwendbar. Glasgefässe sind womöglich mit gut eingeriebenem Glasstopfen zu verschliessen. Wird paraffinierter Kork verwendet, so dürfen die Proben nicht mit Paraffin verunreinigt werden. Roher oder stark poröser Kork genügt nicht.

(3) Die versandbereiten Behälter sind bei kleinen Proben möglichst genau auf Gramm abzuwiegen; das Gewicht ist deutlich auf der Verpackung zu vermerken. Bei Versand in Holzkisten oder in anderen nicht luftdichten Behältern ist die Abwage besonders wichtig.

(4) Die Proben sind aussen mit einem verlässlich befestigten Erkennungszeichen (Bezeichnung der Kohle, Tag der Probeentnahme sowie Probenummer) zu versehen. Ein gegen Unkenntlichmachung geschützter Zettel mit den gleichen Angaben ist auch in die Probebehälter hineinzulegen.

(B) Untersuchung.—Bezüglich der Untersuchung von Kohle steht man in Oesterreich einer Ausgestaltung der Methoden zur Erzielung einer möglichst weitgehenden Vergleichbarkeit der Untersuchungsergebnisse verschiedener Laboratorien mit grossem Interesse gegenüber. Die Gesellschaft für Wärmewirtschaft steht bezüglich dieser Frage mit verschiedenen ausländischen Körperschaften in häufiger Fühlung.

Zur Orientierung über gegenwärtig übliche Untersuchungsmethoden sollen im Nachstehenden beispielsweise diejenigen Methoden angeführt werden, welche bei der Versuchsanstalt für Brennstoffe an der Technischen Hochschule in Wien in der Regel verwendet werden.

Die Immediatanalyse umfasst die Bestimmung von Feuchtigkeit, Asche, Reinkoks und flüchtiger Substanz, woraus rechnerisch die Rohkoksmenge, die Reinkohlenmenge, der Aschengehalt des Rohkokses und der Reinkoksgehalt der Reinkohle bestimmt werden können. Bisher wurde der Feuchtigkeitsgehalt der lufttrocken zur Untersuchung gelangenden Kohle durch Erwärmen der Kohle während einer Stunde auf 106°-110°C rein empirisch ermittelt. Wie jedoch die neueren Untersuchungen ergaben,[1] besitzt diese Methode, besonders bei leicht oxydablen Brennstoffen, mancherlei

[1] "Brennstoffchemie," Jahrgang 1927 und 1928.

Fehler, weshalb auch an dem genannten österr. Institut auf die Bestimmung des Wassergehaltes mit Hilfe von Xylol übergegangen wird.

An die in dem Tiegel mit 1 gr Probe ausgeführte Feuchtigkeitsbestimmung kann gleich die Verkokungsprobe angeschlossen werden. In früheren Jahren wurde wenig Aufmerksamkeit auf die Temperatur bei der Verkokung verwendet und ebenso auch auf das Tiegelmaterial. Erst nach den Untersuchungen von S t r a c h e und M i k a[2] wurde nur Platin bei der Verkokungsprobe für Steinkohle verwendet und die Verkokung selbst bei 900°C 7 Minuten lang durchgeführt. Braunkohlen werden im Rose-Tiegel im Leuchtgasstrom verkokt und der Tiegel darin auch erkalten gelassen. Aus der Differenz zwischen dem Gewichtsverlust der getrockneten Probe und dem der verkokten Probe ergibt sich der Gehalt an flüchtiger Substanz. Stellt man nun die Tiegel schräg auf ein Glühdreieck über eine Flamme, so verbrennt der Reinkoks und es bleibt nur die Asche zurück, welche direkt ausgewogen werden kann.

Für die Bestimmung des Blähungsgrades des Kokses stehen dem genannten österr. Institut 2 Methoden zur Verfügung und zwar:

Entweder die ältere nach L a n t,[3] welche darauf beruht, den Kokskuchen nach Wägung zu paraffinieren und unter Wasser zu stecken und aus dem Volumen der Wasserverdrängung das Rohkoksvolumen zu ermitteln. Einfacher gelangt man nach D o l c h zum Ziel, wenn man den Rohkokskuchen in dem von D o l c h angegebenen pyknometerartigen Gefäss[4] mit Schrott überschüttet und so indirekt das Schrottvolumen feststellt.

Der Aschenschmelzpunkt wird je nach Verwendungszweck der Kohle in oxydierender oder reduzierender Atmosphäre ausgeführt. Bei Durchführung der Bestimmung in oxydierender Atmosphäre bringt man auf ein elektrisch aufheizbares Platinstreifchen einige Körnchen Kohlenasche und beobachtet mit einem Mikroskop unter gleichzeitiger Steigerung der Temperatur des Platinstreifchens, wann ein Niederschmelzen der Asche stattfindet. Ist dieser Zustand erreicht, so stellt man mit einem Hohlborn-Kurlbaum-Pyrometer die Temperatur des Platinstreifens fest. Um die Bestimmung in reduzierender Atmosphäre auszuführen, wendet man einen elektrischen Röhrenofen an, dessen Heizdraht aus Molybdän besteht. Das Einschubrohr des Ofens, welches den pyramidal geformten Aschenkegel von 15-20 mm Höhe enthält,

[2] Zeitschrift "Gas- und Wasserfach," Jahrgang 1926, Seite 1.
[3] Zeitschrift "Brennstoffchemie," Jahrgang 1922, Seite 97.
[4] Zeitschrift "Brennstoffchemie," Jahrgang 1926, Seite 7, 69.

kann mit irgendeinem reduzierenden Gas gefüllt werden. Ein Mikroskop oder auch eine stärkere Lupe gestattet die Beobachtung des Niederschmelzens des Kegels; mit Hilfe eines Chatelier-Pyrometers, dessen Warmlötstelle sich in der Nähe des Kegels befindet, wird die Temperatur des Schmelzpunktes der Asche ermittelt.

Die Heizwertbestimmung von festen Brennstoffen erfolgt nach der Methode von Berthelot-Mahler in einer Bombe aus nicht rostendem Stahl, die zufolge der weiten Verbreitung, die diese Methode besonders in Europa zu verzeichnen hat, nicht näher beschrieben zu werden braucht. Für die Bestimmung von Gasen und leichter flüchtigen Flüssigkeiten, z.B. Benzinen, wird zweckmässiger Weise das Junker 'sche Kalorimeter verwendet. Auch hier erübrigt sich eine genaue Beschreibung des Apparates.

Die Röhrchenentgasung dient zur einfachen Ermittlung der Gasheizwertzahl und der Gas- und Teermenge eines festen Brennstoffes. Als Einwage nimmt man etwa 0,2 gr, entgast in dem von Hiller beschriebenen Röhrchen[5] und sammelt das so erhaltene Destillationsgas in einer Hempel 'schen Bürette durch Reduktion des Gasvolumens, dessen Menge auf 0° 760 mm berechnet werden kann. Der Heizwert des so erhaltenen Destillationsgases wird zweckmässigerweise in einem Kaloriskop nach Strache-Löffler ermittelt. Sollen grössere Kohlenmengen verarbeitet werden, so bedient man sich der Fischer 'schen Schwelanalyse[6] und führt die Bestimmung in der von ihm angegebenen Aluminium-Schwelretorte aus. Je nach Grösse der angewendeten Retorte nimmt man 20-50 gr Einwage. Die Gasmenge wird in einem kleinen Laboratoriums-Gasbehälter gesammelt. Der Teer wird mit dem Wasser zusammen bestimmt und dann das Wasser für sich nach der Xylol-Methode. Die nach dieser Methode erhaltene Gasmenge kann naheliegender Weise wieder auf 0° 760 mm umgerechnet werden. Die Schwelanalyse gestattet ausserdem noch direkte Untersuchung des erhaltenen Schwelgases in Bezug auf die chemische Zusammensetzung und das Litergewicht.

Kohlenstoff und Wasserstoff werden gemeinsam durch Verbrennung im beiderseits offenen, mit Kupferoxyd gefüllten Quarz-Rohr im Sauerstoffstrom bestimmt. Zur Beheizung des Rohres dient ein Gasofen nach Frerich-Normann oder ein elektrischer Röhrenofen. Zum Zurückhalten der Schwefel- und Stickstoff-Verbindungen der Kohle dient ein auf 180° erwärmtes

[5] Zeitschrift des Vereins österr. Gas- u. Wasserfachmänner, Jahrgang 1915, Heft 15.

[6] Zeitschrift für angewandte Chemie, Jahrgang 1920, Seite 172.

Blei-Superoxyd. Die Bestimmungen werden mit etwa 0,2 gr Substanz im Sauerstoffstrom ausgeführt und die Absorptionsgefässe, das Chlorkalcium-Röhrchen und das Natronkalk-Röhrchen, welch letzteres bekanntermassen zu einem Sechstel des Volumens an der Ausgangsseite mit Chlorkalcium gefüllt ist und dem noch ein Kontrollrohr angeschlossen ist, werden stets mit Sauerstoff gefüllt gewogen. Die Stickstoffbestimmung wird auf Grund der mannigfachen Untersuchungen, welche den Nachweis erbrachten, dass die K j e l d a h l - Methode nur einen Teil des in der Kohle enthaltenen Stickstoffes zu bestimmen gestattet, während der Rest verloren geht, nach D u m a s und L a m b r i s[7] bestimmt. Die letztgenannte Methode beruht im Prinzip darauf, dass in das von einem mässigen Kohlensäurestrom durchflossene Rohr gleichzeitig auch reiner chemisch hergestellter Sauerstoff eingeleitet wird, dessen Menge so begrenzt wird, dass sie gerade hinreicht, die im Schiffchen vorhandene Substanz ganz zu verbrennen. Im übrigen ist das Rohr in der gleichen Weise wie nach D u m a s mit Kupferoxyd und am Ausgangsende mit einer blanken Kupferspirale beschickt.

Der Schwefel der Kohle wird in zwei Bestimmungen ermittelt und zwar: einmal nur der verbrennliche Schwefel im Sauerstoffstrom nach L a n t, jedoch unter Anwendung eines einseitig bajonettförmig ausgezogenen Quarzrohres. Weiters werden als Absorptionsgefässe nur mehr die F r i e d r i c h s 'schen Schraubenwaschflaschen,[8] welche mit Brom-Natron-Lauge oder mit ammoniakalischem Wasserstoffsuperoxyd als Absorptions-Flüssigkeit beschickt sein können, verwendet. In einer separaten Probe wird der Aschenschwefel durch vorhergehendes Veraschen von etwa 2-3 gr Kohle, je nach Schwefelgehalt der Kohle, durch 10 Minuten langes Auskochen der feingepulverten Asche in 10%-iger Sodalösung, der man noch etwas Brom zusetzen kann, bestimmt. Nach dem Ansäuern mit Salzsäure und Filtrieren der Sodalösung kann man, wie üblich, mit Barium-Chlorid Aschenschwefel im Filter bestimmen.

Die noch übrigen in der Versuchsanstalt für Brennstoffe in Wien ausgeführten Untersuchungsmethoden sind nicht einheitlich festgelegt, da deren Ausführung sehr wesentlich von der Art des untersuchten Materials abhängig ist.

Die heute so wichtige Bestimmung der Reaktionsfähigkeit des Kokses ist noch zu wenig einheitlich festgelegt, als dass eine richtungsgebende Methode angegeben werden könnte. Vom Standpunkte der Gaserzeugung in Generatoren bei Verwendung von

[7] Zeitschrift "Brennstoffchemie," Jahrgang 1927, Seite 1.
[8] der Firma Greiner & Friedrichs, Stutzerbach, Thüringen.

Koks als Ausgangsmaterial empfiehlt es sich die von K o r e v a a r[9] abgeänderte K o p p e r 'sche Methode anzuwenden. Die Aufarbeitung des Teeres wird entweder nach der Destillations-Methode, oder auf chemischen Wege unter Ausnützung des Verhaltens der einzelnen Komponenten gegen Petroläther, Säure und Lauge vorgenommen.

RÉSUMÉ

(SPECIALLY PREPARED)

The regulations discussed in this paper have been adopted in Austria as the result of investigations by the "Society for Fuel Economy," Vienna.

The errors, due to wrong methods of selection of coal samples, are considerably greater than the irregularities in technical analysis. To obtain an average sample, a number of pieces of varying size, in proportion to their occurrence in the coal to be tested, must be taken, as usually the ash and moisture content varies with the size of the coal.

The preparation of a test sample requires three operations:—

(1) Selection.

(2) Preparation of the actual quantity required for the laboratory test.

(3) Packing and despatch.

The surest method of selection is carried out during loading operations; a shovelful can be taken at regular intervals whilst the coal is travelling down the chute. For a total quantity of 1,000 Kg. about 10 or 20 Kg. should be withdrawn. For 10,000 Kg. (one railtruck), about 50 Kg.; for larger quantities 50 Kg. per railtruck. Larger samples are required if the size of the coal varies much.

If the coal is loaded in small tubs or other containers, whole tub loads must be selected at regular intervals. To get an average selection from stored coal is rather difficult, as it is essential that samples should be taken from the centre and bottom as well as the surface of the dump. For chemical analysis at least 3 Kg. are required; but as much as 100 Kg. may be necessary for technical industrial tests.

The preparation of the laboratory sample is best done on a smooth clean floor. The larger pieces are crushed and the whole well mixed. After dividing diagonally into four equal parts, two opposite piles are removed. This process is continued until the required quantity is left. Delay in carrying out this operation must be avoided to preserve the moisture content. For special moisture tests a little of the coal should be enclosed in an airtight container before the preparation of the laboratory sample is commenced. A few unbroken pieces also may be sent under separate cover. It is advisable to prepare three equal samples in important cases, one each for the laboratory, the consumer and the supplier. They must be packed in airtight glass or tin containers; wooden cases should only be used in those instances where the moisture content is considered of little importance and where it is known that atmospherical influences will not impair the composition of the coal. Paper or cardboard should not be used. Tin boxes should be soldered, while putty may serve to keep the glass containers airtight. If cork soaked in paraffin is used, care must be taken not to soil the sample with the paraffin. All

[9] Sammlung Kohle-Koks-Teer, Band 14, Verlag Wilh. Knapp, Halle a.d.S.

packages should be marked with their accurate weight (in grammes). The date of selection, a description and number of the sample must be recorded in and outside the package.

To give an example of the methods of analysis at present in use, those employed in the laboratories of the Technical University, Vienna, are considered. The moisture content was formerly determined by heating the coal for one hour at a temperature of 106° to 110°C. The latest experiments, however, have shown,[1] principally with fuels of an oxidisible nature, that this method is unsatisfactory. For this reason the xylol is employed for determination of the moisture content at this Institute. The coking test can be carried out in connection with the moisture test (1 gramme). Formerly little attention was paid to the crucible and temperature used in coking. Experiments by Strache and Mika have led to the general use of platinum crucibles for the coking test of hard coal; the temperature is kept at 900°C. for seven minutes. Brown coals are carbonised in a Rose crucible by the application of a gas flame. The loss of weight during carbonisation represents the amount of volatile substance present. The coke is then burnt by tilting the crucible over a flame and the remaining ash weighed.

Two methods are available for the determination of porosity. The older one, by Lant, is to treat the cake of coke with paraffin, and by submerging it in water determine the coke-volume from the displacement. A simpler method, by Dolch, is to place the cake in a pyknometer-like container (as referred to by Dolch in "Brennstoffchemie" 1922, p. 97) cover it with shot and so determine the volume indirectly.

The melting point of the ash is determined either in an oxidising or reducing atmosphere. For the first method a few grains of ash are placed on an electrically heated platinum strip and kept under observation with the aid of a microscope while the temperature is raised until the ash melts. At this stage the temperature of the platinum strip is taken with a Hohlborn-Kurlbaum-pyrometer. For the second method, an electric tube furnace is required, the heating wire of which is of molybdenum. The tube containing the pyramidical piece of ash of 15 to 20 mm. height, can be filled with any reducing gas. The melting is watched with the assistance of a microscope and the temperature determined with a Chatelier pyrometer.

The calorific value is obtained by the well-known Berthelot-Mahler process in a stainless steel bomb. For very volatile substances, such as benzin and gases, a Junker's calorimeter is used.

For the gasification test, about 0·2 gr. are placed in a tube, described by Hiller[2] and the quantity of gas, collected in a Hempel-burette, is calculated to 0°C. and 760 mm. The calorific value of the gas obtained is best determined in a Strache-Löffler caloriscope. If larger quantities are to be handled, about 20 to 50 gr. are tested in an aluminium retort as described by Fischer,[3] the gas being collected in a small gasholder. Tar and water are determined together and then the water separately by the xylol method. The amount of gas obtained is calculated at 0°C., 760 mm. This method of analysis permits direct investigation of the chemical composition and density of the gas. Carbon and hydrogen, are determined at the same time by the combustion

[1] "Brennstoffchemie," 1927-1928.
[2] Zeitschr. d. Vereins österr. Gas- u. Wasserfachmänner, 1915, No. 15.
[3] Zeitschr. für angewandte Chemie, 1920, p. 172.

of about 0·2 gr. in a tube, filled with copper oxide, through which a current of oxygen is passed. A Frerich-Normann gas stove or an electric tube heater can be used. Lead oxide heated to 180°, is used to retain the sulphur and nitrogen compounds. The test is carried out in a current of oxygen and both absorption tubes, the calcium chloride and soda-lime tubes, are always weighed, filled with oxygen. It is well known that the latter should be filled at the outlet to one-sixth of its volume with calcium chloride.

As the Kjeldahl method determines only part of the nitrogen content, the method described by Dumas and Lambris[4] is employed, a current of chemically pure oxygen being passed through the tube at the same time as carbon dioxide, the quantity of oxygen being just sufficient to effect the complete combustion of the substance. The tube contains copper oxide and a copper spiral at the outlet.

For the determination of sulphur, two tests are made. The first obtains combustible sulphur with the aid of a bajonette-shaped quartz tube. Friedrichs' wash bottles[5] filled with sodium bromide solution or ammoniated hydrogen peroxide, are used for the absorption. For the second test the ash of 2 to 3 gr. coal is powdered and boiled for ten minutes in a 10 per cent. solution of soda, to which a little bromide may be added; the solution is acidified with hydrochloric acid and filtered. The sulphur content of the ash may then be determined in the filtrate with the aid of barium chloride.

Other methods in use at this Institute are not standardised as their application varies with the nature of the material to be tested.

No definite methods are yet available for the determination of the reactivity of coke. For the manufacture of producer gas from coke, Kopper's method, amended by Korevaar, is advisable. The tar can be either subjected to distillation or chemical action with the aid of petroleum ether, acids and solutions.

[4] "Brennstoffchemie," 1927, p. 1.

[5] Fa. Greiner & Friedrichs, Stutzerbach, Thüringen.

A PRACTICAL COMPARATIVE BASIS FOR THE CALORIFIC VALUE OF COAL

POLISH NATIONAL COMMITTEE, WORLD POWER CONFERENCE

STANISLAW FELSZ

Paper No. B2

CONTENTS

STANDARD VALUE FOR THE CALORIFIC VALUE OF THE COAL USED ON THE POLISH RAILWAYS
RÉSUMÉ

The calorific value of the coal used on the railways varies over a very wide range, and, for this reason, figures relative to coal consumption are useless for purposes of comparison, unless certain adjustments are made and certain factors are introduced. This is particularly true with regard to the comparison of the coal consumption in various countries.

Similarly, the variation in the calorific value of the coal renders it difficult to compare the coal consumption with the service rendered by and the evaporation realised in the locomotives, though a knowledge of these is of considerable importance when the question of fixing and calculating coal prices arises.

It has, therefore, become necessary to introduce the conception of a hypothetical "standard coal" of a definite calorific value. I am recommending as a standard, a coal with an effective calorific value of 6,320 Calories per kilogramme, since this figure is not only representative of the average calorific value of the coal used, but possesses, in addition, the advantage that it simplifies calculations according to a decimal system if the total heat of steam be assumed to be 632 Calories and the equivalent factor per horse-power-hour be also taken as 632 Calories.

If the calorific value be denoted by K Calories per kilogramme,

the heat content of the steam by P Calories per kilogramme, and the percentage efficiency of the boiler by $E\%$, then the evaporation (k) is expressed in terms of the formula

$$k = \frac{E\,K}{100\,P} \text{ kilogrammes of steam per kilogramme of coal.}$$

If the ratio $\frac{K}{P}$ be ten, then $k = \frac{E}{10}$.

If the best possible efficiency of the boiler realisable by complete combustion of the combustible portion of the fuel be expressed as a function of the rate of firing by use of one of the numerous approximate formulae which have been proposed, for instance, by the formula

$$E = 80 - 0{\cdot}04\,b,$$

where b represents the quantity of coal burnt in kilogrammes per square metre of grate area per hour in terms of "standard coal" (6,320 Calories), there is obtained the following approximate formula for the evaporation under the same conditions and as a function of the rate of firing

$$k = 8 - 0{\cdot}004\,b.$$

In the same way, when the value of k is fixed, the rate of firing (b) and the efficiency of the boiler can readily be calculated.

In like manner, the following calculations are facilitated:

(1) The efficiency of the engine when the consumption per horse-power-hour is known, and *vice versa*.

(2) The evaporative value of the coal when the efficiency of the boiler is known and *vice versa*.

(3) The consumption of coal per horse-power-hour from the known efficiency of the unit and *vice versa*.

RÉSUMÉ

En égard aux différentes valeurs calorifiques des houilles utilisées par les chemins de fer, les résultats publiés relatifs au rendement de la houille doivent subire un correction par l'introduction de coefficients tenant compte des houilles de différentes qualités. Pour éviter cette correction, l'auteur propose d'introduire une conception de la "houille normale," correspondant à 6320 Cal/kg, ce qui répond à la qualité moyenne de la houille et en même temps facilite le calcul de beaucoup de coefficients caractéristiques.

DÉTERMINATION DES MATIÈRES VOLATILES À BASSE TEMPÉRATURE DANS LES CHARBONS

(DETERMINATION OF VOLATILE MATTER IN COAL BY LOW TEMPERATURE METHODS)

CZECHOSLOVAKIAN NATIONAL COMMITTEE, WORLD POWER CONFERENCE

R. VONDRÁČEK

Paper No. B3

CONTENTS

INTRODUCTION—DESCRIPTION OF APPARATUS—RESULTS OF TESTS—CONCLUSION—RÉSUMÉ

Pour apprécier les combustibles solides en fait de leur teneur en matières volatiles, on peut se servir ou d'une méthode de cokéfaction à haute température ou bien d'essais exécutés à de basses températures. Dans le cas de lignites et de houilles sèches, cette deuxième méthode peut devenir préférable, pour la raison qu'elle correspond plutôt aux conditions de leur utilisation.

Dans ses études sur le bilan matériel de la carbonisation et sur la classification des charbons, l'auteur a été conduit à chercher une méthode de dosage des matières volatiles à de basses températures qui, étant simple à exécuter, n'en serait pas moins exacte. On est arrivé enfin à une méthode bien satisfaisante, dont le principe consiste en l'emploi d'un bain de soufre bouillant. Le point d'ébullition du soufre étant une constante (444°C.), on obtient des résultats très bien comparables. Cette température est encore assez élevée pour démontrer les différences dans la composition chimique et dans l'allure des combustibles d'une manière bien prononcée. On peut même soutenir que les diversités dans la nature chimique des charbons deviennent moins évidentes si la carbonisation est exécutée à une température plus élevée.

L'appareil employé à l'exécution de cette méthode (Fig. 1) est aussi simple que possible. Le bain de soufre consiste en une éprouvette de verre à parois mince, ayant 25 mm. de diamètre. En vue de protéger les parois contre l'action directe de la flamme, on fixe à la

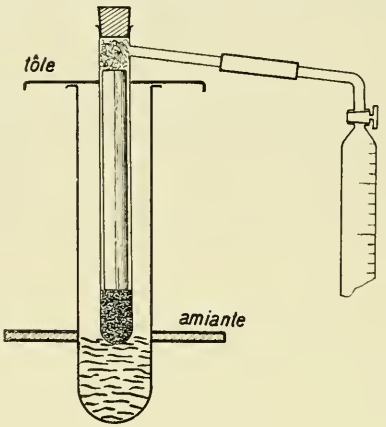


Fig. 1.

partie inférieure de l'éprouvette une plaque d'amiante. L'orifice de l'éprouvette est couvert d'une feuille métallique, par préférence en aluminium. L'échantillon du charbon examiné est placé dans une petite cornue, formée d'un tube en verre dure, munie près de son orifice d'un conduit latéral qui peut être adapté à une burette à gaz. Le diamètre intérieur de la cornue est de 10 mm., sa hauteur de 170 mm. On ferme la cornue par un bouchon en caoutchouc. Pour prévenir l'entrainement du charbon pulvérisé par des gaz et, à la fois, dans le but d'expulser de la cornue une partie de l'air qui y est contenu, on met sur l'échantillon une baguette de verre, ayant 8 mm. de diamètre et 120 mm. environ de longueur. Le bout supérieur de la baguette se trouve alors de 1 à 2 cm. au-dessous du conduit latéral de la cornue. L'espace au-dessus de la baguette est rempli d'amiante, servant à la retention de gouttes d'eau et de goudron. Il est bien aisé de régler l'ébullition du soufre de manière que ses vapeurs n'atteignent pas le bord, mais que leur condensation se termine 3 cm. environ au-dessous du bord de l'éprouvette. Dans ce dernier cas les vapeurs de soufre ne se font guère remarquer dans l'air du laboratoire, même si l'appareil n'est pas placé sous une hotte.

La couche de soufre fondu a 4 cm. environ de hauteur et la cornue est fixée de façon à toucher par son fond la surface du liquide.

Le volume de l'air expulsé de la cornue chauffée est déterminé dans un essai à blanc, dans lequel le charbon est remplacé par des

perles de verre ayant le même volume que l'échantillon de charbon (1,5 gr. de charbon correspond à 2,5 gr. de verre).

La prise d'essai est de 1,2 à 2,0 gr., selon la teneur en gaz du combustible examiné.

Un point bien important est le choix d'une durée convenable de la chauffe. Après quelques essais préliminaires d'une demi-heure et quelques-uns d'une heure, l'auteur s'est décidé pour les chauffes de 2 heures, le dégagement de gaz après ce temps étant déjà si faible que les fautes provoquées par des irrégularités initiales dans le chauffage deviennent tout à fait négligeables. Toutefois, dans le but d'abréger la durée de l'essai, l'auteur se propose d'élaborer cette méthode aussi pour des chauffes plus courtes. Voici quelques chiffres démontrant la vitesse du dégagement de gaz de divers combustibles (Tableau I).

I. VOLUME DU GAZ EN CC., DÉGAGÉ D'UN GRAMME DE COMBUSTIBLE BRUT

No. de l'échantillon.	Durée de la chauffe en minutes.			
	30	60	90	120
1	—	11	14	16
3	35	52	60	67
5	—	26	29	31
14	—	59	61	64
16	—	66	71	72
17	49	57	60	63
18	71	77	81	82

On trouve le volume du gaz dégagé en déduisant du volume mesuré la quantité d'air déterminée par l'essai à blanc. Il est évident que dans un travail précis on ne néglige point les changements de la température de l'air ambiant. Comme liquide de fermeture nous employons dans la burette une solution saturée de NaCl. On peut diminuer les inexactitudes provenant de la dissolution de CO^2 dans le liquide de fermeture, si l'on enferme dans la burette une certaine quantité (10 ou 20 cc.) d'air, en sorte que la pression partielle du CO^2 est abaissée dès son entrée dans la burette.

La détermination du volume de gaz est suivie, en général, par le dosage du CO^2, soit en commun avec l'hydrogène sulfuré, soit à part, le H^2S étant d'abord enlevé par absorption dans une solution acide de sulfate de cuivre. La nécessité et la méthode d'enlèvement de H^2S méritent encore une étude plus profonde.

Pour déterminer le poids du semi-coke, on enlève de la cornue le bouchon d'amiante, on la nettoie du soufre adhérent et, après un

court séchage à 105°C., on la pèse. Si l'on rempli bien les conditions de la durée de chauffe, la température étant toujours la même, les résultats des essais parallèles s'accordent d'une manière satisfaisante (Tableau II).

II. RÉSULTATS DE QUELQUES ESSAIS PARALLÈLES

No. de l'échantillon.	Rendements d'un gramme.				
	Essai.	Coke %	Gaz cc.	CO^2+H^2S cc.	CO^2 seul cc.
1	(*a*)	95,4	16,4	2,9	—
	(*b*)	95,6	17,0	—	1,0
	(*c*)	—	17,1	—	0,9
5	(*a*)	86,6	29,8	3,0	—
	(*b*)	86,5	30,1	3,5	—
	(*c*)	—	30,1	—	3,3
17	(*a*)	64,5	62,0	28,7	—
	(*b*)	64,1	60,6	29,2	—
	(*c*)	—	61,6	—	26,7
19	(*a*)	59,7	80,3	48,2	—
	(*b*)	60,0	80,8	47,7	—
	(*c*)	—	80,9	—	44,1

La méthode a été appliquée à une série de 20 combustibles, allant de l'anthracite jusqu' au bois. Le Tableau III indique la composition chimique de ces substances, tandis que les résultats des expériences exécutées sur les mêmes substances sont inscrits dans le Tableau IV. Les chiffres figurant dans ce tableau-ci se rapportent à la matière combustible pure (exempte d'humidité et de cendres) et les volumes de gaz total et de CO^2 sont réduits à la température de 15°C.

Les combustibles étant rangés d'après leur teneur en oxygène, on remarque aisément que, dans la majorité des cas, l'accroissement de teneur en oxygène est accompagné d'un accroissement de rendement en gaz total et, surtout, en CO^2. Les exceptions les plus frappantes concernent des substances riches en hydrogène.

Il serait sans doute bien intéressant de savoir s'il y a des relations définies entre les résultats de la carbonisation et la composition chimique. Un travail antérieur, exécuté dans notre laboratoire[1] dans le même but, ne nous a pas donné, à cet égard, une réponse assez nette, d'une part, parce que le nombre des combustibles examinés était assez limité, et d'autre part pour la raison que la

[1] Vondráček und Perna, Stoffbilanz der trockenen Destillation verschiedener Brennstoffe, Montanistische Rundschau, 1926, Nr. 8 u. 9.

température bien élevée (800°) de ces essais pouvait effacer les différences initiales.

III. COMPOSITION CHIMIQUE DES COMBUSTIBLES EXAMINÉS

No.	Genre.	Humidité.	Cendres.	Dans le combustible pur.				
				C	H	S	N	O
1	Charbon à coke ...	0,8	16,1	88,6	4,57	2,18	1,79	2,84
2	Anthracite ...	0,9	11,1	90,4	4,31	1,50	1,57	2,22
3	Cannel coal ...	1,0	10,8	83,2	7,58	1,93	1,41	5,93
4	Charbon à coke ...	1,7	4,0	86,1	5,02	0,60	1,58	6,77
5	Charbon à gaz ...	1,7	16,2	84,4	5,10	—	—	—
6	,, ,, ...	1,9	3,7	84,2	5,12	0,96	1,45	8,24
7	Houille mate ...	1,7	20,2	84,4	4,91	0,53	0,70	9,51
8	Houille sèche ...	2,5	12,0	82,7	4,97	0,99	1,52	9,84
9	Charbon à gaz ...	2,2	5,3	82,1	5,00	1,25	1,60	10,05
10	Boghead	4,9	4,5	79,0	7,48	1,25	0,75	11,70
11	Charbon à gaz ...	3,3	5,1	80,9	4,84	1,00	1,37	11,88
12	Lignite cireux ...	4,9	10,1	77,1	8,22	1,60	0,94	12,44
13	Houille sèche ...	3,8	18,1	80,0	4,88	1,30	1,20	12,62
14	Lignite cireux ...	6,4	7,5	74,1	8,84	1,43	0,35	15,28
15	Lignite	8,5	8,5	74,1	5,55	1,50	—	—
16	,, ...	12,2	7,9	73,5	5,77	1,46	1,21	17,80
17	,, ...	12,1	4,9	72,6	5,61	1,49	1,51	18,77
18	,, ...	15,0	8,7	67,7	4,80	2,39	0,76	24,30
19	,, ...	13,4	20,9	65,1	5,24	2,69	1,58	25,40
20	Bois de pin ...	5,2	0,3	50,9	5,86	0,06	0,06	43,16

IV. RÉSULTATS MOYENS DES EXPÉRIENCES

Nos.	Rendements d'un gramme de combustible pur.			Le graphique indique.		Chaleur de combustion.	
	Coke %	gaz total cc.	CO^2 cc.	H	O	calculée.	mesurée.
1	94,7	21,2	1,5	5,05	2,5	8.711	8.737
2	98,4	11,5	1,3	4,3	2,2	8.655	8.630
3	64,1	72,1	7,4	7,5	6,7	8.824	8.820
4	86,4	33,1	3,4	5,15	7,0	8.390	8.472
5	85,6	36,7	4,0	5,1	8,2	8.263	8.340
6	84,4	37,3	3,5	5,3	7,0	8.383	8.368
7	87,7	33,3	3,7	4,9	8,3	8.285	8.260
8	88,7	43,3	6,4	5,15	10,5	8.009	8.030
9	82,7	40,2	4,7	5,1	9,5	8.080	8.120
10	53,3	89,8	18,5	7,5	11,7	8.385	8.425
11	89,2	37,6	7,0	4,75	11,7	7.805	7.820
12	44,2	90,0	20,9	7,1	13,0	8.115	8.296
13	82,9	41,3	10,4	4,8	13,0	7.685	7.714
14	37,5	114,5	34,0	8,8	15,5	8.270	8.243
15	70,4	72,1	26,8	5,55	16,7	7.396	7.390
16	69,2	88,8	35,1	5,75	18,5	7.268	7.230
17	71,6	74,4	32,2	5,45	18,2	7.220	7.242
18	64,4	124,0	61,7	5,7	23,3	6.700	6.358
19	59,3	123,6	67,1	5,6	23,4	6.613	6.310
20	33,9	108,5	50,3	—	—	—	—

Tout d'abord, vu la nature complexe et hétérogène des combustibles naturels et artificiels, l'existence de telles relations apparaît assez doutable. Mais il faut aussi reconnaître que la méthode proposée ci-dessus permet de prendre en considération non seulement les rendement en coke, mais encore ceux en gaz et enfin la composition chimique du gaz. Certes, on a déjà proposé des méthodes de dosage des matières volatiles, admettant les mêmes possibilités (bien connu à cet égard est la méthode de M. Lessing[2]), mais on n'en a pas fait usage, à notre connaissance, pour l'analyse indirecte des substances examinées. Toutefois, la question mérite bien la peine d'être étudiée.

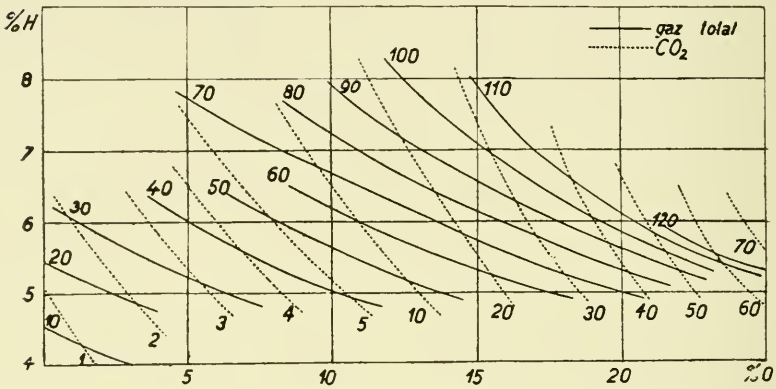


Fig. 2. Rendements (cc.) en gaz total et en CO^2, d'un gramme de combustible pur, ayant une teneur définie en oxygène et hydrogène.

L'auteur s'est contenté, pour le moment, de prendre en considération assez sommaire les relations entre la composition chimique du combustible et les rendements en gaz total et en CO^2. En se servant d'une représentation graphique, on arrive à un système de points qui, avec un peu d'idéalisation, peuvent être réunis en deux systèmes de courbes, dont un représente les volumes en gaz total et l'autre ceux en CO^2. Ces rendements sont donnés dans le graphique (Fig. 2) en fonction de la teneur en oxygène et de celle en hydrogène. On voit que les courbes des volumes égaux sont réparties dans le réseau assez régulièrement.

En acceptant les données de ce graphique comme justes, on pourrait donc juger que chaque combustible, caractérisé par une certaine teneur en oxygène et en hydrogène, donne dans des conditions d'expérience, un rendement défini en gaz total et en anhydride

[2] Rep. VIII Intern. Congress Appl. Chem. 10, 195, 1912.

carbonique. Ces rendements étant donnés, on pourrait, de retour, conclure à une composition définie de la substance examinée. L'auteur a ajouté dans le Tableau IV les valeurs des teneurs en O et en H, telles qu'elles se présentent en vertu des courbes idéalisées de la Fig. 2. Les écarts des valeurs réelles sont, en général, assez petits. Il faut prendre en considération que la teneur en oxygène n'est pas toujours exactement connue, surtout pour les combustibles riches en cendres. On arriverait peut-être à des accords plus parfaits, si la position des courbes était un peu changée. Ceci est vrai en particulier pour les courbes aux environs de 25 pour cent d'oxygène, où un effet opposé commence à avoir lieu, c'est-à-dire une diminution du rendement en gaz à la teneur ascendante en oxygène.

La représentation graphique deviendrait probablement plus claire si, au lieu des rendements en gaz total, on y enregistrait les volumes de gaz exempt de CO^2.

On peut de même s'intéresser à la question, dans quelle mesure les chaleurs de combustion, calculées sur la base des valeurs pour H et O, prises du graphique, et des teneurs connues en S et N, s'accordent avec les valeurs réelles. Le calcul a été fait moyennant la formule dérivée par l'auteur.[3]

$$Q = (89{,}1—0{,}062\ C')\ .\ C + 270\ (H—0{,}1\ O) + 25\ S,$$

dans laquelle C' désigne la teneur en carbone de la substance pure (exempte de cendres et d'humidité). On voit du Tableau IV que l'accord est dans ce cas-ci même plus parfait qu'il ne l'est pour les teneurs en oxygène, ce qui pourrait dénoter que les chiffres pour l'oxygène, trouvés par voie analytique, sont moins exacts.

Cependant, il n'était pas dans l'intention de l'auteur de suggérer dans le mémoire présent une méthode d'analyse indirecte des combustibles. L'élaboration d'une méthode assez sûre, pour être applicable, doit faire l'objet d'études ultérieures. Toutefois, l'auteur croit avoir démontré qu'une telle tentative n'est pas nécessairement absurde, quoiqu'il faille s'attendre à ce que dans quelques cas spéciaux (mélanges de divers combustibles, charbons oxydés par aération, etc.) le graphique ne donne pas des chiffres sûrs.

RÉSUMÉ

The paper suggests the use of a bath of boiling sulphur for carbonisation tests at low temperature. The boiling point of sulphur (444°C.) is high enough to indicate the different behaviour of various fuels. Since the temperature of the sulphur bath is very constant, the method can give identical results in the hands of different operators. The bath is formed by a simple test tube and the sample is placed in a cylindrical retort tube of hard glass, provided with an outlet in the side. The latter is similar to the well-known retort of Dr. Lessing. Besides the weight of the semi-coke, the total volume of the evolved gas and the volume of carbon dioxide are determined. The author studies relations existing between the chemical composition of fuels and the volumes of gas and CO_2, and is of the opinion that in many cases it should be possible to estimate approximately the chemical composition and the calorific value of fuels from the results of the low-temperature carbonisation tests. A diagram, corrected to represent ideal conditions, shows the results of tests carried out with the proposed method on twenty different fuels, the time of heating being two hours in each case.

DE L'HYGROSCOPICITÉ DES CHARBONS

(THE HYGROSCOPIC QUALITIES OF COAL)

CZECHOSLOVAKIAN NATIONAL COMMITTEE, WORLD POWER CONFERENCE

R. VONDRÁČEK

Paper No. B4

CONTENTS

INTRODUCTION—DESICCATION AND HUMIDIFICATION—RESULTS OF TESTS—CONCLUSION—RÉSUMÉ

Parmi les propriétés physiques des charbons il n'y a peut-être nulle autre qui soit définie si insuffisamment que l'hygroscopicité. Généralement, on se contente de définir l'humidité hygroscopique telle que le combustible pulvérisé retient après sa dessiccation à l'air de 20°C ayant l'humidité relative de 50 pour cent. Le plus souvent on ne s'occupe guère des conditions de température et d'humidité de l'air et on considère la détermination de l'humidité dans le charbon séché à l'air seulement comme un expédient analytique. Cependant, il s'agit ici d'une propriété qui non seulement se trouve en rapport avec le degré de transformation du combustible et qui a même été appliquée à l'appréciation de son pouvoir calorifique, mais encore qui présente une importance considérable pour l'emmagasinage et le transport des combustibles. Il n'y a aucun doute que la dessiccation à l'air de combustibles très humides amène leur dislocation et pulvérisation et il est bien probable que le degré et les changements d'humidité, étant liés à la capillarité, ont une influence importante et point encore assez appréciée sur l'oxydation lente ou spontanée des charbons.

Le manque d'une définition exacte pour l'"hygroscopicité" des combustibles et le manque d'une méthode assez convenable à sa détermination tiennent peut-être à la complexité des phénomènes respectifs, en raison de laquelle le même charbon sous des conditions extérieures identiques peut avoir une teneur bien différente en

humidité. Il n'est pas assez reconnu que la dessiccation des charbons n'est pas un processus strictement reversible, mais qu'elle est souvent accompagnée d'une hystérésis assez prononcée.

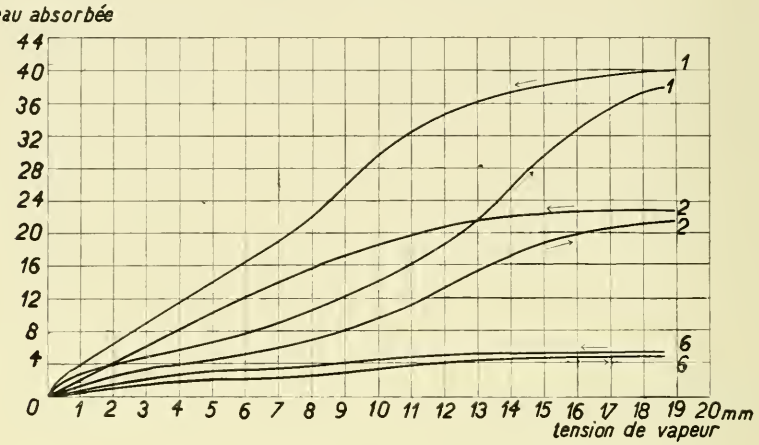


Fig. 1. Courbes de dessiccation et d'humidification de charbons.

Fig. 1 représente trois exemples des expériences faites dans notre laboratoire, concernant un lignite (no. 1), une houille sèche (crétacée, no. 2), et un charbon à gaz (no. 6). L'axe horizontal indique les tensions de vapeur d'eau dans l'atmosphère ambiante, l'axe vertical marque en grammes les quantités d'humidité liées à 100 gr de combustible sec et exempt de cendres. Les flèches indiquent si la courbe est relative à la dessiccation ou à l'humidification. Les échantillons examinés ont été placés dans un exsiccateur à vide en présence d'eau ou d'acide sulfurique plus ou moins dilué, d'une concentration connue. L'air a été enlevé par aspiration. On a procédé avec la dessiccation en partant d'eau pure et en allant graduellement jusqu'à l'acide sulfurique concentré, après quoi on a opéré l'humidification d'une manière inverse. Les échantillons ont été exposés à la vapeur d'eau d'une tension définie, tant qu'il y avait un changement du poids, ce qui éxigeait quelquefois plusieurs semaines. La température était de 17 à 22°.

On remarque le fait assez curieux que la substance complètement desséchée n'absorbe pas l'humidité dans la même mesure qu'elle l'a perdue durant la dessiccation et que ce n'est qu'à l'atmosphère saturée de vapeur d'eau que l'humidité de la substance devient approximativement égale à celle qu'elle a eue avant la dessiccation. Ce sont surtout les lignites qui se distinguent par une hystérésis d'humidification très prononcée.

Il s'agit ici d'un phénomène connu de la théorie de capillarité,[1] qui, entre autres, a été étudié par M. Zsigmondy sur le gel de silice. On est même parvenu à calculer sur la base de telles courbes le rayon des capillares.

Pour la pratique, il suit des phénomènes décrits ci-dessus qu'un combustible, ayant été bien desséché, pourrait être considéré comme une substance peu hygroscopique, tant que l'humidité relative de l'air serait aux environs de 50 pour cent, mais qu'en cas d'une élévation de l'humidité dans l'atmosphère la teneur en eau du combustible pourrait brusquement monter de plusieurs centaines de pour cent. Voilà un point qui mérite bien de ne pas être méconnu.

On observe aussi de la figure et du tableau, dans lequel sont enregistrés les résultats des expériences, que les différents combustibles se distinguent non seulement par leur teneur en humidité à l'atmosphère saturée de vapeur, mais encore par leur pouvoir de perdre leur humidité, si la tension de vapeur dans l'atmosphère baisse. Pour un rabaissement de la tension de vapeur de 18,7 à 7,8 mm., donc de 58 pour cent, on voit l'humidité initiale des combustibles se changer de la manière suivante:

Échantillon No.	1	2	3	4	5	6	7	8
Diminution d'humidité en gr.	11,6	6,6	4,2	9,1	2,9	1,5	1,4	0,8
do. en pour cent ...	44	30	23	50	35	28	42	45

La diminution de la teneur en humidité n'est alors point proportionnelle à l'abaissement de la tension de vapeur et son degré, pour divers combustibles, est bien différent.

On pourrait donc conjecturer que l'état saturé d'humidité soit le plus convenable à l'appréciation des propriétés hygroscopiques des charbons. Toutefois, nous considérons une telle méthode comme assez risquée, vu le fait que l'humidité des combustibles placés dans une atmosphère saturée de vapeur d'eau change très sensiblement avec la température, qu'il y a même de la condensation d'eau liquide dans les échantillons et que, si l'on n'use pas de précautions spéciales, il est bien difficile d'arriver aux résultats justes. Pour le moment, nous considérons que la marche la plus sûre est d'exposer l'échantillon d'abord à une atmosphère saturée de vapeur d'eau aux environs de 20°C. et de le mettre ensuite dans un exsiccateur en présence d'acide sulfurique dens. 1,35 (ayant à 20° un tension de vapeur d'eau de 8,2 mm). Après un séjour de 4 à 7 jours dans cette atmosphère on dose la teneur en humidité de la façon habituelle. Pour prévenir une oxydation lente de l'échantillon, il est recommandé d'enlever l'air de l'exsiccateur par aspiration.

[1] voir Freundlich, Kapillarchemie, II. Auflage, p. 913.

QUANTITÉ D'EAU ABSORBÉE DANS 100 Gr. DE COMBUSTIBLE SEC.

Température °C.	21	18	17	17	19	19	22	22	20	19	20
Tension de vapeur, mm. Hg. ..	18,7	11,1	7,8	5,2	1,5	0,0	1,6	8 6	9,9	13,8	18,1
1. Lignite I	26,3	22,7	14,7	9,5	2,4	—	1,0	6,1	9,2	14,4	24,3
2. Charbon crétacé	22,2	19,9	15,6	10,8	2,9	—	2,4	7,6	10,8	16,1	22,7
3. Lignite II	18,4	17,0	14,2	10,2	2,7	—	2,3	7,6	11,0	15,5	19,5
4. Lignite cireux	18,0	14,0	8,9	6,3	2,1	—	1,6	4,6	6,6	10,1	16,5
5. Semi-coke	8,5	7,6	5,6	3,7	1,0	—	1,1	3,6	5,8	11,7	13,0
6. Charbon à gaz	5,3	4,6	3,8	3,0	1,0	—	1,0	2,7	3,6	4,4	4,7
7. Cannel coal	2,6	1,5	1,2	0,8	0,3	—	0,5	1,0	1,2	1,6	3,5
8. Houille mate	1,8	1,3	1,0	0,9	0,3	—	0,4	0,9	1,1	1,5	1,7

Il faut mentionner que l'allure irréversible de la dessiccation des charbons a été déjà constaté dans les recherches de MM. H. C. Porter et O. C. Ralston.[2]

RÉSUMÉ

The drying of coals is not strictly a reversible process, and the humidification of a dry fuel in atmosphere of a gradually rising tension of aqueous vapour is accompanied by a comparatively large hysteresis (time lag). It is emphasised that there is no satisfactory method of determining the hygroscopicity of coal, which property is of great importance in connection with storage and transportation, due to the slacking and oxidation, which occur through this phenomenon.

[2]Bureau of Mines, Techn. Paper 113 (1916).

GENERAL REPORT ON SECTION B

SAMPLING AND TESTING OF SOLID FUELS

DR. A. PARKER

The following papers have been communicated for consideration by this section of the Conference :—

B1 Sampling and Testing of Coal (Austria).

B2 A Practical Comparative Basis for the Calorific Value of Coal (Poland), by Stanislaw Felsz.

B3 Determination of Volatile Matter in Coal by Low-Temperature Methods (Czechoslovakia), by R. Vondrácek.

B4 The Hygroscopic Qualities of Coal (Czechoslovakia), by R. Vondrácek.

G3 The Use of Gross and Net Calorific Values for the Purpose of Guarantee Tests (Germany), by N. F. Nissen.

The subject matter of these papers may be classified under the headings :—

I Sampling.

II Examination of samples.

- (*a*) Proximate analysis.
- (*b*) Ultimate analysis.
- (*c*) Calorific values.
- (*d*) Tests not so frequently required.
- (*e*) Special tests.

III Interpretation of results.

The first paper, B1, presented under the auspices of the Gesellschaft für Wärmewirtschaft, Vienna, gives a general account of those methods recommended by this authority for general adoption in Austria in the sampling and examination of coal and coke.

Communications B3 and B4, prepared by R. Vondrácek and presented by the Czechoslovakian National Committee, describe a low-temperature method for the determination of volatile matter in coal and an investigation of the hygroscopic qualities of coal under different conditions.

The paper, B2, by Stanislaw Felsz, of Poland, introduces the conception of a standard coal as regards calorific value, with the object of simplifying the comparison of coals used on the Polish railways.

Communication G3, by N. F. Nissen, for the Vereinigung der Deutschen Dampfkessel-und-Apparate-Industrie, Düsseldorf, und Allgemeiner Verband der Deutschen Dampfkessel-Ueberwachungs-Vereine, München, has also been included in this section, since it discusses the use of gross and net calorific values of solid fuels for guarantee tests, and thus deals with the interpretation of results dependent on determination of calorific values.

During recent years considerable attention has been directed towards the standardisation of methods of sampling and examination of solid fuels for commercial purposes, and in some cases, authorities of recognised standing have already prepared definite specifications which will, presumably, be reviewed periodically and, if necessary, modified.

For the purposes of many special investigations and researches, standardised analytical methods would be unsuitable, and further, their too extended use might conceivably operate against progress; but even in pioneer work, difficulty is frequently experienced in attempts to compare the results of different investigators, owing to the wide divergencies in analytical methods adopted.

There is no doubt, however, that for general commercial and technical requirements, the adoption of standard methods would prove distinctly advantageous, especially if the particular methods laid down received international approval. It is believed that this session of the Conference can serve a useful purpose, provided the questions considered and discussed are limited to methods which might be employed in connection with technical tests as distinct from special investigations. This necessarily means that only those methods of sampling, testing and analysis should be brought forward which could be completed in reasonable time, compatible with required accuracy and with reasonable facilities and apparatus.

It is too much to hope that in one session it will be possible to arrive at specifications which would receive universal approval, but the discussion should constitute a useful preliminary towards the formulation of international standard methods. This Conference will have merited its organisation if it succeeds in

promoting closer co-operation between the recognised authoritative bodies already studying the subject in different countries.

The complete process of evaluation of a solid fuel may be divided into two main sections, sampling and examination of the samples, each of which may be further sub-divided as indicated by the following arrangement :—

I—Sampling.

(*a*) Selection of large sample representative of the consignment.

(*b*) Preparation from the large sample of laboratory or test samples.

II—Examination of samples.

(*a*) Proximate analysis, including moisture, volatile matter, fixed carbon, and ash.

(*b*) Ultimate analysis, including carbon, hydrogen, sulphur, nitrogen, oxygen, and ash.

(*c*) Calorific values, gross and net.

(*d*) Tests not so frequently required, *e.g.*, specific gravity and caking index of coal, true and apparent specific gravities and porosity of coke, reactivities and ignition temperatures, melting points of ash, composition of ash, etc.

(*e*) Special tests for particular purposes, *e.g.*, carbonisation assay of coal, including examination of products.

Sampling

Although it may not be possible to specify detailed instructions which could be followed in all circumstances in taking samples representative of a consignment of solid fuel, the procedure and precautions to be observed, as outlined in the paper by the Gesellschaft für Wärmewirtschaft, of Vienna, will doubtless meet with general approval. In fact, the general procedure is already adopted by a large number of fuel technicians.

(*a*) *Proximate Analysis*

The most usual method of ascertaining the moisture content of solid fuels includes the preliminary determination, with comparatively wet fuels, of the loss in weight on drying a large sample in air at a temperature rather higher than that of the surrounding atmosphere. The air-dried sample is then estimated for moisture by determining the loss in weight of a small sample when heated in an oven at about 105°C. for a specified time. Certain types of

coal, however, when heated to 105°C. in air, undergo oxidation and errors result. To obviate this oxidation, many methods have been devised, both direct and indirect, and the method recommended in the first paper is that in which a sample of coal (usually 30 to 50 grammes) is placed in a flask with 200 c.c. xylol and distilled, the water carried over with the xylol and condensed being accurately measured. Methods employed by other authorities to prevent oxidation include that of drying the sample at 105°C. in an oven supplied with an inert gas free from oxygen.

The determination of volatile matter is carried out in Austria by a method almost identical with that prescribed in America. The sample is heated in a platinum crucible for seven minutes at 900 to 950°C. It is well known that with certain fuels, *e.g.*, high temperature coke, this method does not give reliable results, and requires modification to prevent a variable loss due to combustion. One modification is that used in Austria for brown coals, which are heated and cooled in a Rose crucible supplied with inert gas.

(*b*) *Ultimate Analysis*

Carbon and hydrogen are almost universally determined by combustion in oxygen, according to the recognised procedure for the determination of these elements in organic compounds. Several methods have at various times been suggested for the estimation of the elements by examination, either gravimetrically or volumetrically, of the gas remaining after combustion of the sample with oxygen in a calorimetric bomb, but in general, these methods either do not reduce the work involved or are less accurate.

The results of systematic investigations of the different forms of sulphur in coal have been published during recent years, but usually it is sufficient to ascertain the total sulphur content of a fuel, or at most, the combustible sulphur and the sulphur in the ash. For total sulphur, the Eschka method is perhaps most employed, but other methods, of which combustion with sodium peroxide might be mentioned, are extensively used. In Austria, the total sulphur is obtained by addition of the sulphur gasified in oxygen in a combustion tube and the sulphur content of the ash of the sample. Sulphur might also be conveniently determined in conjunction with the calorific value in a bomb calorimeter.

Nitrogen is usually determined by various modifications of the

Kjeldahl method. Several recent investigations have led to the conclusion that the Kjeldahl process probably leads to results which are too low. For this reason, some authorities, including the Gesellschaft für Wärmewirtschaft, of Vienna, have adopted modified forms of the Dumas method of combustion with copper oxide. The great disadvantage of the Dumas method, however, is that it is not nearly so convenient and requires much more skill and attention than the Kjeldahl process.

The determination of the amount of ash in a solid fuel by the usual method, although simple, is not altogether satisfactory, in that the ash is obtained in a different state of oxidation from that in the original fuel. This change in state of oxidation of the ash constituents has an important influence on the difference figure which represents the quantity of oxygen in the fuel. A satisfactory direct method of estimating oxygen is urgently required, for there is no doubt that reliable figures for this element would aid in the elucidation of several problems of fuel technology.

(*c*) *Calorific Values*

The well-known method of determination of the gross calorific value of a solid fuel by combustion in a bomb of the Berthelot-Mahler type is almost a universal standard, but there appears to be a lack of uniformity in the data employed in making the necessary deduction to obtain the net value. In the first place, the precise meaning of net value requires rigid definition, with special reference to the amount of heat to be deducted from the gross value for each unit weight of water in the products of combustion. The amount of the deduction is dependent on the final temperature to which it is assumed the water vapour is cooled without condensation.

(*d*) *Other Tests*

The caking index of coal is generally measured by a modification of the Campredon test, and represents the maximum number of parts of sand which may be mixed with one part by weight of coal to produce a coherent coke when heated to about 950°C. Objections to this method have been raised on the grounds that sand is an inert material very different from the substances ordinarily employed in carbonisation, and that it is difficult to ensure different supplies of sand of the same quality. Other

methods suggested, however, do not appear to possess any marked advantages over the modified Campredon test.

The apparent specific gravity of coke is obtained from the weights and volumes of typical pieces. The volume may be obtained by several methods, two of which are mentioned in the first paper. Reference might also be made to the method of weighing pieces of coke in air and in mercury. Tests for apparent gravity of coke, however, would seem to require systematic investigation before a satisfactory standard could be recommended.

Further study of the factors associated with the properties of solid fuels as regards reactivities towards steam and carbon dioxide and as regards ignition temperature is necessary before any approach to uniformity in evaluating these properties, now assuming so much importance, can be expected.

(*c*) *Special Tests*

The determination of the volatile matter removed from coal under low-temperature conditions is discussed in communication B3, and a test is described. The sample of coal, 1.2 to 2 grammes, is placed in a hard glass tube heated to 444°C. in the vapour of boiling sulphur. Some interesting results and possible deductions are given.

The factors which account for the difficulties in attempts to determine the hygroscopic powers of coals have been investigated by R. Vondrácek, of Czecho-Slovakia, and the results are described in paper B4. The main difficulty results from the fact that the absorption of moisture by coal is not strictly a reversible process. A test is suggested for obtaining comparative values of hygroscopicity.

The carbonisation assay of small samples of coal with the object of evaluating different coals for commercial carbonisation processes is rapidly becoming of great importance. It is doubtful, however, whether the time is yet ripe for the establishment of standard methods of assay. In the first place, it is not easy in a laboratory apparatus to obtain results from which the yields of products in a particular large scale process could be predicted with sufficient accuracy. Secondly, many technical processes are widely different from one another.

Evaluation from Calorifi Values

Two papers, B2 and G3, discuss the methods of evaluation of solid fuels from the results of determination of calorific values. Stanislaw Felsz suggests the conception of a hypothetical standard coal with a gross calorific value of 6,320 cals. per gramme (11,376 B.Th.U. per lb.) in the evaluation of coals for use in raising steam for the railways of Poland. A calorific value of 6,320 cals. approximates to the average quality of the coal employed and simplifies calculation if the total heat of steam be taken as 632 cals. per gramme and the heat equivalent of one-horse-power-hour be taken as 632 cals. The evaporation per unit weight of standard coal is then exactly one-tenth of the percentage efficiency of the steam raising unit.

According to the specification for conducting guarantee tests of steam-raising plants in Germany, during a period of two years efficiencies have been reported on the basis of both the gross and the net calorific values of the fuel consumed. The gross calorific value assumed that the initial and final temperatures of the fuel and products of combustion were 0°C.; the net value assumed that the dry gases were cooled to 0°C., but that the water vapour was cooled only to dew point. The experience gained has led to the conclusion that efficiencies based on gross value are not satisfactory and that net values only are required. Calculations are made and curves are given to show that the efficiency of a particular installation, consuming the same fuel throughout, may change considerably if derived from the gross value, with variation in the moisture content of the fuel, but that the efficiency derived from the net value is liable to only small variation.

DISCUSSION

TUESDAY, SEPTEMBER 25 (AFTERNOON).

Section B

SAMPLING AND TESTING OF SOLID FUELS

Chairman—CAPTAIN SINNATT (Great Britain)

The General Report was presented by Dr. A. Parker.

DR. A. PARKER (Great Britain) opening the discussion, said that the method of sampling suggested in the paper from Austria consisted in taking a bulk sample wherever possible during loading or unloading a consignment of coal. If the loading was done by conveyor then a small amount would be taken at suitable intervals, or if the coal was delivered in small packages, then a certain number of packages would be taken to represent the bulk of the coal. The main point brought forward was that the sample must contain pieces of coal of different sizes, in exactly the same proportion as in the original consignment because the composition of the larger pieces of coal might be quite different from the composition of the smaller coal, especially as regards ash content. As regards proximate analysis, the first item was the determination of moisture, and he thought that if the different authoritative bodies representing the different nations could get together, some satisfactory simple standard test could be universally accepted. The American standard for the determination of volatile matter was fairly satisfactory for bituminous coals, because the volatile matter drives away the air above the surface of the coal, and thereby to some extent prevents oxidation, but with high-temperature coke, and even with anthracite and using what might be termed a tight fitting lid to the platinum crucible, considerable oxidation occurred and differences of perhaps 2 per cent. in the volatile matter might result. Several methods had been devised and published for getting over this difficulty and here, again, he thought a method might easily be decided upon which would be satisfactory for universal adoption. The heating up of coke or anthracite for volatile matter determination must be carried out in an inert atmosphere, and cooling must also take place in an inert atmosphere if oxidation was to be avoided. Methods of ultimate analysis for carbon and hydrogen should be readily settled. There was still some dispute about the nitrogen determination, for different workers seemed to have reached diverse opinions on the reliability of the Kjeldhal and the Dumas methods, and that was a point which might well be discussed. Sulphur was again a test that required some discussion and further work. It was also necessary to devise a satisfactory method of determining the oxygen content of the fuel directly and not as a difference figure. In the

paper by Prof. Vondráček an attempt was made to correlate figures from ultimate analysis and for the calorific value of coal with results of the determination of volatile matter under low temperature conditions. The development of a useful relationship of this kind required reliable figures for oxygen. At the present time, the oxygen figures included errors and did not represent the true amount of oxygen in the original coal. As regards calorific value, the method of ascertaining the gross value in the bomb calorimeter was fairly well standardised, but to obtain the net value, different authorities made different deductions for each unit weight of the water condensed. In some cases it was assumed that the water was cooled to dew point, and the dew point naturally varied according to the proportion of moisture present. That method, therefore, did not give a uniform figure for deduction. Others assumed that the water vapour was cooled without condensation to 100°C. That was a point which required study by the authoritative bodies of each country, as, for example, the new Committee of the British Engineering Standards Association in this country. With reference to the interpretation of results, the main point brought forward in the papers was whether the gross or net calorific value should be used for the purpose of guarantee tests. This was a problem which could not very easily be settled. For steam raising plants it seemed, from the work done in Germany, that the net value was the more suitable, but the net value could not be used for all purposes. For example, in the carbonising industries, the procedure was to take a certain weight of coal of a definite gross calorific value and to carbonise it and determine the heat value of the resulting products. In a case of that kind it was absolutely essential to use the gross value as a basis. The net value would be practically meaningless. Net value for guarantee tests would have to be limited to tests with particular types of plant and apparatus. As regards the standardisation of methods, a resolution had been brought forward at the meeting of Section A in the morning advocating co-operation between the different national committees with a view to standardisation, and, personally, he thought this could not be too highly stressed. It would be impossible to decide on details at a Conference of this character, since a large amount of work would be necessary, but if the different bodies could be brought into touch with one another they might be able to arrive at a few standard tests. Every test could not be standardised because each country would require different tests for certain purposes. Some tests, however, could be standardised, and that was a point he had stressed in the General Report.

The Chairman, in calling upon Mr. le Maistre, the Secretary of the Engineering Standards Association of Great Britain, said this was an entirely independent body working in conjunction with those associated with any particular industry. Within the last eight months the Association had done a great deal of work upon the subject of standardising methods of sampling and analysis of coal, but before commencing this work it had called together a conference

representative of every interest concerned with the production and utilisation of coal. Committees had been appointed, and Panels were at work upon various aspects of the subject, and results of their deliberations could be expected in the near future.

Mr. C. E. le Maistre (Great Britain) said his Association was an independent body. There was no Government control, although it had Government support, and he believed the activities of the Association were fairly well known on the Continent and in America. He felt it would be wise, perhaps, to clear the ground in view of the resolution that had been passed at the morning meeting of Section A, when there were about 150 people present and, as far as he could see, about fifteen people held up their hands in support of the resolution in favour of some international action being taken, whilst the remainder did not vote one way or the other. Therefore, he would explain what was being done in this country and how it came about. The Fuel Research Board, as a section of the Department of Scientific and Industrial Research, in the course of its work had to come to some understanding on the very points which were the basis of the present discussion in order that they might complete or get on with the work of the national survey of the coal resources of this country. The report which the Board issued and which had been sent very widely abroad, had been in some cases taken as representing authoritative British standards, but in this country it was known that nothing was farther from the thought of the Department than that this report should be taken as the law of the Medes and Persians, and as the standard for this country. The report was prepared solely for the purposes of the Board, and to prove that it was only necessary to state that it was the Fuel Research Board which initiated the movement for standardisation in these matters under the ægis of the British Engineering Standards Association. It was at the instigation of the Fuel Research Board that the Association called a conference, some nine or ten months ago, which was very fully attended by every interest that could be got in touch with. The coal owners, the scientific people, the commercial people, were all at this conference, and the Fuel Research Board very kindly placed at the disposal of the B.E.S.A. the report that had been issued in order that it might be used as a basis. The Board also placed at the disposal of the B.E.S.A. all the investigations which had been carried on for a number of years in order that the matter need not be commenced *de novo*. That Conference brought out very clearly indeed that what was required in this country was some commercial agreements in order that a more scientific selling of coal might be brought about, *i.e.*, whilst the Conference realised fully the scientific interest of the matter it also realised the industrial side. It had always appeared to the B.E.S.A. that industrial standardisation was only about 15 per cent. technical and about 85 per cent. human. It was not the least bit of good putting up fine technical standards and then waiting till kingdom come for the commercial people to adopt them. That would not do the country any good, and the consequence was that

whilst the scientific side was being fully borne in mind there had been formed two sub-committees, one on sampling and one on analysis, and also five panels dealing with moisture, volatile, ash, sulphur and calorific value, upon all of which the industrial side was fully represented. These committees had in mind all the time that the object was to bring about some industrial agreement on these points so that some collective effort might be made for the good of the industry. Naturally, in doing that, they had in mind all the time the desirability of bringing into their discussions their colleagues across the water, but before taking international action an endeavour must be made to put our own house in order—and the same applied to other countries—and then to pool the knowledge that had been gained. All that took time, and it was for that reason that he laid stress on the fact that industrial standardisation was such a human problem. He assured the Conference that the international side had not been at all forgotten in this country. Indeed, some months ago the B.E.S.A. appointed a liaison or foreign correspondence committee, but it could not go very far forward until the other National Committees had begun to see daylight on their problems. This liaison committee, however, numbered among its members those who were in touch with the competent people in foreign countries. Two or three of the interested countries were perfectly alive to this subject and were most willing to come together and help the British Committee in the problems before them. In addition to this liaison committee, regional committees had been formed in this country and there were committees in Cardiff, Newcastle, Glasgow, Sheffield and Manchester, so that the work in this country was very fully organised both as to principles and as to details. It seemed to him that so far as Europe was concerned, Great Britain had made great progress in this matter and would appear to have a more detailed organisation than any other country. If, therefore, this Conference desired international co-ordination, then the country that had done so much should be the country to be asked to take the first steps. It was very important indeed that the commercial aspect should be appreciated and insisted upon right through, and in no country should the pure technician be too much in charge of the work, otherwise there was a danger of proposals being put which, whilst technically ideal, would not recommend themselves to the commercial mind. The commercial people wanted something as simple as possible which would help them in making comparisons of tenders and enable the purchasers to know what they were getting.

Dr. E. W. Smith (Joint Technical Secretary) said that the resolution passed in the morning was completely innocuous and was not intended in any way to conflict with the work of the B.E.S.A., or any other similar body. It was not a resolution of the Executive, but it came from Sweden. At the same time, he wished to point out that the Executive realised that all the wisdom did not lie in the B.E.S.A., in spite of their unbounded faith in B.E.S.A. Neither did all the wisdom lie in Great Britain; and from the purely psychological point of view, whatever the facts might be, it was absolutely

fundamentally necessary that it should be recognised that there might be some value in all other countries, and that therefore the door should be left wide open for the encouragement of co-operation. Even if a resolution might be innocuous, it was also advisable that there should not be one but many bodies that were acting and were saying that there should be co-operation. He had implicit faith in the B.E.S.A. and its work. He had a very close acquaintance with what it was doing in connection with coal, and the British National Committee was absolutely satisfied to leave their interests in the hands of B.E.S.A. There was no suggestion to the contrary, but the Conference would do well to accept any general recommendation that there should be co-operation. It was not the intention that the resolution passed in the morning should tie the hands of B.E.S.A. in any way.

Ing. Dr. Giacomo Forte (Italy) spoke with regard to the standard value of calorific power from the point of view of one engaged upon the Italian State Railways. As was stated in the General Report, Mr. Felsz introduced the conception of a standard hypothetical coal, and stated that a coal possessing 6,320 calories was an average coal used on railways. On the Italian railways, however, a coal having a higher calorific value was used, *viz.*, 7,800 calories to 8,200 calories, and a similar quality of coal was also used in Germany, Switzerland and France. Moreover, the heat obtained per kg. of steam from any coal used on railways or in power stations depended upon the steam pressure, the quantity of water trained by steam, which might be overheated, and the temperature of the water introduced into the boiler, which might be pre-heated by the exhaust steam. Therefore, it could not be said that a formula expressing the ratio between the calorific power of a coal and the number of calories absorbed per kg. of steam would be a constant. It might apply in a number of cases, but not generally. Therefore, it would be necessary to make corrections for different countries because of the varying qualities of coal used for different purposes.

Mr. G. W. Himus (Great Britain), speaking with regard to the proximate analysis of coal, said that as regards the moisture and volatile matter determination, the chief objection that was made, as a rule, to the drying of coal in an oven, was that oxidation might take place in certain circumstances. At the Imperial College of Science they claimed to have got over that difficulty by the use of a steam-heated vacuum oven. The coal was introduced into an oven containing a series of horizontal plates which were heated by steam coils. The heating of the coal continued for 1½ hours, by which time the change in weight eased. There was no evidence that oxidation had taken place. The xylol method was likely to give very accurate results, but from the technical point of view he was inclined to favour the oven method, because not only did the xylol apparatus occupy a good deal of bench space, but it could not be used for any other purpose, whereas the vacuum oven could be used for drying other things than coal, and it gave reasonably accurate results. Any satisfactory test for the determination of

volatile matter must fulfil the following conditions: the control of the temperature must be accurate and it must be reasonably easy. There must be no interference with the results brought about by oxidation during heating or cooling of the sample. It must be certain that at whatever temperature was chosen the coal was robbed entirely of its volatile matter by the heating. From the purely theoretical point of view there was an obvious objection to the use of platinum, and owing to its well-known catalytic effect it was safer to avoid the use of it in the vessel containing the sample to be heated. Moreover, certain coals, for example, some Welsh coals with 10 to 12 per cent. volatile matter, decrepitated violently when heated suddenly; they jumped right out of the crucible and needed to be heated slowly if a test was to be conducted without loss. The method in use at the Imperial College of Science was to heat the coal in a small silica tube which was enclosed in an outer larger silica tube under such conditions that the gas evolved from the coal forced water out of a bottle into a second bottle, the water in the second bottle acting as a seal, so that the coal was heated and cooled in contact with its own gas, and thus all risk of oxidation was avoided. In dealing with high-temperature cokes where there was insufficient gas to force the water out of the first bottle and form a seal in the second, it was possible to introduce an inert gas into the heating tube, which was heated in an electric furnace. There was a platinum-platinum-rhodium thermo-junction alongside, so that the temperature could be controlled accurately and the rate of heating could be arranged to suit the coal which was being tested. Normally, with a coal that did not decrepitate, the tubes were put into a temperature of 90°C. in the furnace, but in the case of coals that decrepitated the tubes were pushed into the furnace at air temperature and the temperature gradually increased. In that way there was no risk of inconsistency in the results due to decrepitation. Furthermore, the heating could be continued for such a time that it could be certain that all the volatile matter had been driven out of the coal. This was shown by the fact that no more gas bubbled through the water seal. The consistency of the results obtained was shown by the fact that they were within 0·1 to 0·2. In the case of a coal having 30 per cent. of volatile matter, the figures would fall between 29·9 and 30·1 every time, and in the case of two determinations carried out simultaneously the consistency was even greater than that.

Mr. L. S. de Waard (Holland) said that Prof. ter Meulen, of the University of Delft, had worked out several new and elegant methods for the determination of all the constituents of coal, including oxygen, all of which were printed in a small booklet which had been published and had been translated into English and German. Regarding the oxidation of coke and anthracite by the determination of volatile matter, by using the small American crucible and a No. 3 Meker burner; this oxidation was not greater than 0·3 per cent. for a heating time of seven minutes at 900°C. The decrepitation of the anthracite was prevented by mixing it with equal parts of a good coking coal

containing a known quantity of volatile matter. As to the use of gross or net calorific value, it seemed to him that it made little difference which was used so long as it was known which was used. The calorific value, gross or net, was not a good value for the specification of a fuel when used alone, nor was it a good figure to take when comparing boiler efficiencies. It was necessary to know much more about the characteristics of the fuel. In Holland the net calorific value was used, because then the real losses in the flue gases were known, and to say that the evaporation heat of the water in the stack gases was not usable was not sound reasoning in the present stage of boiler development. It was not by accident that the Americans, who always used the gross value, also tried to use the condensation heat of the water in the flue gases. Perhaps the manufacture of stainless steels would bring the solution of this problem nearer. In Holland, boiler efficiency was often determined by determining all the losses and subtracting the number so obtained from 100. This was often better than determining the efficiency directly from the evaporation.

Prof. R. Vondráček (Czechoslovakia) referred specially to the paper from Austria, and said that whilst there were some time ago in different countries some divergencies of opinion as to the best methods of analysis of coal, he now had the impression that the research work carried out to find the possible errors and inaccuracies in the various methods had not been wasted, and that the methods now employed by the different workers do not vary very much. Indeed, there were some upon which all chemists would now agree. The Austrian paper did not deal with the details of the determination of the calorific value, as that was the method generally adopted. He, therefore, recommended this method for general consideration on account of the possibility of standardisation in certain details. For instance, there was the preparation of the sample of different low-grade coals, rich in moisture or ashes, where certain precautions could be taken to ensure complete combustion in the bomb. In the proposals contained in the Austrian paper he found described only the determination of the combustible sulphur and the ash-sulphur, but not that of the total sulphur content. There was no doubt that the combustible sulphur had the most injurious effect during combustion in the furnace, but the conditions in which the ash was burned in the crucible and in the furnace under practical conditions were very different, and the proportion of sulphur going into the gases would not be the same in each case. It was a difficult task to burn coal in a crucible in such a definite manner that the sulphur content of the ash would always be the same. As the ash was heated to a higher temperature its sulphur content decreased rapidly. Therefore, he preferred the determination of the total sulphur content in coal, as this described the quality of a coal in a more definite manner. The two papers which he himself had presented to the Conference dealt with more theoretical subjects, but he hoped that they might also have a significance for the practical evaluation of solid fuels. The method of determining the volatile matter in coal at the temperature of boiling sulphur was very

simple and exact. The determination of the volume of the gas evolved and its CO_2 content was very easily carried out, and might replace more complicated methods of evaluation of fuels approximately. One of the papers also dealt with the importance of having an exact definition of "hygroscopicity," and also of having a definite method of determining it. It was a curious thing that the term "hygroscopical humidity" was often used, yet there was no exact definition of it, although this quality was very important for practical purposes—storage and transport—and also in scientific research into coal. In conclusion, Prof. Vondráček said he was optimist enough to believe that we should soon arrive at international standards, and his country, rich in coal and lignites, was ready to take part in this work.

Dr. H. Löffler (Austria), speaking in German, gave a brief account of coal testing methods carried out in Austria, pointing out particularly that in determining the water contents in lignites, the xylol method was in use instead of the drying method at 105°C. He recommended, however, the use of tetrachlorethane instead of xylol, as tetrachlorethane was not a combustible possessing, with regard to its solubility in water, the same character as xylol.

As to the determination of the calorific value of solid fuels, he recommended the correction formula of Regnault-Pfaundler. The field of application of this formula was of a far greater extent than with other correction formulæ in use; this meant that in applying the Regnault-Pfaundler formula there was greater liberty in the choice of the pre-heating temperature of the water and the quantity of the weighed substance than in using similar formulæ. It was found, too, that a determination in which the correction factor amounted to more than 6 per cent. of the apparent difference in temperature should be refused as incorrect. As to the determination of the size of the pores of the coke, Dr. Löffler referred to a series of tests he had carried out in order to characterise the distribution of the pores of the coke. The usual methods of determining the volume of the pores only gave the total volume of the pores without taking any account of their distribution. By saturating a piece of the coke with a liquid with a certain power of refraction of light, and then placing this piece in a second liquid with a known power of light refraction, differing from the light refraction power of the first liquid as much as possible (the two liquids must be miscible with each other), it was possible to obtain, by taking refractometer values at certain intervals, a curve characterising the distribution of the pores in the piece of coke. If the pores were few, but large, the two liquids would mix with each other very rapidly, and the final value of refraction could be taken soon. If, however, the pores were numerous but small, the mixture would proceed very slowly and the refractometer values would change very slowly.

Dr. H. B. Cronshaw (Great Britain) called attention to a method of truck sampling of coal which he described as the pipe method. Probably others had used this method before, and if so, he would

like to have their criticisms of it because it was a very convenient and fairly rapid method, and was in use fairly extensively, he believed, in the United States. He had had occasion recently to make a rapid survey over a very wide area of the coals available for a specific purpose, and had found that a satisfactory comparison of the general characteristics of coals could be made by building up the seams from the coal loaded into the trucks and testing an average sample. It could then be taken that the ash would be at a minimum and the volatiles at a maximum. These and other data enabled a number of coals to be eliminated, and the rest could then be subjected to more precise sampling by a combination of (1) underground sectioning, and (2) sampling from the truck by the pipe method, whereby a 3-in. pipe, 4 ft. long, was driven into the truck of coal at suitably chosen points, the pipe contents being then heaped together and reduced in bulk in the usual manner. As regards the type of crucible used for making coking tests, he had replaced, for industrial purposes, the usual fireclay crucible by silica, as the drawback in the case of fireclay was that the weight of the crucible was subject to variations due to absorbtion of moisture and the products of combustion. Further, with the silica crucible the rate of heat transmission was much more rapid. In the case of a strongly swelling coal, when a silica vessel was used, there was danger of loss owing to a sudden evolution of gas, and in order to obviate this he had departed from the usual practice of inserting the crucibles directly into a furnace heated at a high temperature and had adopted the plan of reducing the temperature at the start to, say, 600°C., and then raising it gradually to 800°C. over a period of half an hour, thus obviating possibility of loss due to too rapid heating at the start. Another advantage of this method was that it enabled one to compare the swelling powers of the coal. Another matter was that it was useful to know the softening temperature of coals; this might be done by powdering the coal, moulding it into pyramid form, raising the temperature in an inert atmosphere, and then noting the temperature at which the cone bent. In the author's laboratory Dr. G. S. Haslam had evolved a modification of Dr. Foxwell's apparatus for measuring the variations in resistance to flow of an inert gas offered by coal when being heated at a prescribed rate. The results were of considerable assistance in choosing coals suitable for gas producers and for low-temperature carbonisation processes with internal heating. Also, Dr. Cronshaw had designed a laboratory retort by means of which it was possible to follow the physical changes in a charge of coal during carbonisation.

Dr. F. V. Tideswell (Great Britain) stressed the importance of ultimate analysis of coal, because this gives the truest guide, so far as available, to the nature of a coal and, indeed, to its utilisation, a fact which perhaps was not yet generally realised. Ultimate analysis would be of great importance in the future in the technical classification of coals. In several papers it had been stressed that the ash content of a coal was not the mineral matter which accompanied the coal. Actually, the ash content was considerably lower

in amount than the mineral matter; therefore, it followed that the acceptance of such a low value affected materially the value of determinations calculated on the ash-free coal as compared with on the pure coal. That had been realised for many years. It was shown by Parr how the correction could be applied to the ash to enable the calorific value of the coal to be referred to a true coal material. That work seemed to have been forgotten, because in none of the papers was there any reference to any method which would enable us to refer any determinations made back to the true coal material. Actually it was not difficult to do so. It was possible to apply a fairly simple correction to the ash which would enable an adequate correction to be made to the values obtained and to refer them back to the true coal material. The materials of the mineral matter were mostly the clays and shales which contained water of constitution. That water of constitution was a difficulty because it was a variable amount, and it was impossible to determine its amount in any particular case without a great deal of trouble. It was, however, possible to make an estimate of it, and a figure of 9 per cent. seemed adequate. Actually, it varied from 5 to 15 per cent., and generally between 7 and 13 per cent. If one assumed that there was present in the clays and shales accompanying coals water of constitution amounting to 9 per cent. of their weight, that would give on the ash that was left, which was 91 per cent., a correction amounting to 10 per cent., and that addition to the shale ash of 10 per cent. would correct satisfactorily for the water of constitution. The remaining constituent which gave trouble was the presence of iron pyrites, and a correction could be made for that. According to Parr an addition of half the total sulphur present would give an adequate correction for the presence of pyrites, but he preferred to use the iron content and make a correction of 4/7ths of the iron content. The final corrected value is mineral matter=1·1 ash+ 4/7 Fe. That had been found to give an adequate correction both theoretically and practically. The remaining constituents of the ash, such as carbonates or other iron salts, could be corrected for separately. That, however, was not necessary because the correction of 10 per cent. for the water of constitution satisfactorily and adequately made a correction for the carbonate or iron salts which were present. Inter-actions occurred in the ash which made it unnecessary to go to greater accuracy, and unless there were more than 5 to 10 per cent. of carbonate present it was unnecessary to make a separate correction. This method had been worked out not only for research application but to meet the requirement of an accurate estimation of the carbon in coal. The total range of carbon content in coal of the bituminous type was of the order of 16 per cent., from 78 to 94 per cent., and it followed that an error of $\frac{1}{2}$ per cent. in the carbon was of material importance. Undoubtedly, in the first place, samples should be asked for as free from mineral matter as possible, and when that had been carried to its limit it was necessary then to apply the correction he had mentioned. He did not think the correction method was too difficult to apply to

commercial work. The only other determination that was required after those normally made was of the iron in the ash, and that was a very rapid process, involving the solution of the ash in sulphuric acid and titration by one of the usual methods.

As to the oxygen content; it had been urged that the direct determination of the oxygen content was urgently required, but he had never considered that it had the great value sometimes attributed to it. The main error in oxygen determination by difference was not in the determination of hydrogen and carbon and other constituents, but the error belonging to the ash, and when a direct determination of oxygen had been made it would still be essential to apply the correction mentioned for the mineral matter present.

Mr. A. Worsley (Great Britain) remarked that whatever system of analysis was adopted should be acceptable to the commercial world, both to sellers and buyers. If dry coals and hydrous coals were lumped together it would pass the wit of any chemist to devise a system which would be acceptable to the producers and users of both types of coal. By the existing method of analysis, lignites showed a low value on account of their high moisture content, whereas if the dry method of analysis were used, air-dried lignites would be found to come up the scale and would appear to possess a value which they never realised when used. That was especially a climatological matter. In the case of a very dry climate, such as that of Spain in summer time, it would be found that lignites freshly brought to the surface had a very high moisture content and a low carbon content, but, under the influence of dry and hot winds, this lignite lost a large quantity of water, and when it arrived at the consumer's premises it was in a dryer condition than when it was first analysed.

To maintain the classification of *dry* and of *hydrous* coals it might be advisable to use a standard which allowed hydrous coals to contain 20 per cent. moisture (with an up and down scale for dryer and wetter grades); this being the minimum of water that air-dried hydrous coal was likely to hold. Wetter lignites would have to add extra bulk to make up for shortage of dry weight, whereas artificially-dried lignite could be subject to the dry coal standard without special proviso.

Herr F. zur Nedden (Germany) spoke of some danger in applying the usual methods of drying in testing lignitic coals because the residue, owing to its capacity for absorbing gases, often showed a tendency to re-increase in weight after a certain degree of dryness had been reached. He further thought it would be wise that a motion should be brought forward informing the National Executive Committee that it was the wish of the Conference that it should take in hand the question of international agreement on testing methods. In doing so, it would be advisable to go forward step by step. Several national organisations were already considering this matter, and probably the Americans had gone farther than any other nation. At the moment, perhaps, it was too much to expect that international agreement could simultaneously be reached on all

methods of testing fuel, but he was expressing the view of the German National Committee when he asked the International Executive of the World Power Conference as a first step to endeavour to find some means of international agreement as regards *calorific value*. In these circumstances he submitted the following motion:—

> Whereas there is no uniformity in the practical application of the gross or net calorific value of fuel, solid, liquid or gaseous, either within the several countries or as between the producers and consumers of the fuel, or internationally, and Whereas such uniformity, as convincingly pointed out in Paper G3 and other papers, is considered to be most desirable for correctly comparing efficiencies and fuel costs; Be it resolved that the International Executive Council of the World Power Conference shall exert every effort to ensure international agreement on these matters.

Mr. C. E. le Maistre (Great Britain) said that as an ordinary member of the Conference, he had much pleasure in seconding the motion. Whilst doing so as an ordinary member of the Conference, he could not quite divorce himself from the fact that he was taking some part in co-ordinating efforts in this country along exactly the lines suggested in the motion, and he therefore suggested that in sending this motion forward to the Executive Council it should be stated that as the standardisation organisation in this country had been working for practically a year on this matter it would be quite prepared, if the International Executive Committee thought it right, to prepare an interim report on the present position and also to act as the centre for the gathering and exchange of ideas from the various bodies.

Dr. R. Lessing (Great Britain), supporting the proposal, said that international agreement on methods of analysis was absolutely essential. A great deal of work had been done in Great Britain by the British Engineering Standards Association and previously by the Fuel Research Board. Tests of calorific value were of very great importance, and it might be that their standardisation would be the easiest starting point. He also supported the suggestion of Mr. le Maistre that the work that had been done by the B.E.S.A. should be collected in an interim report which by no means need be regarded as final, but would be subject to further discussion. This should be submitted to the other co-operating countries and their organisations for their comments and, if possible, approval, with a view to final international adoption.

Dr. E. W. Smith (Joint Technical Secretary) said, on behalf of the International Executive Council, that this motion could be accepted, but not with the addition suggested by Mr. le Maistre. It must be left to the International Council to handle this matter in any way it thought fit. It had a responsibility to all other nations which were not necessarily represented that afternoon, and if the B.E.S.A. would trust the International Executive Council there would be no doubt that all the good work that had been done by B.E.S.A.

would be taken advantage of. If Mr. le Maistre would write officially on behalf of the B.E.S.A., putting forward the suggestion he had made, there was no doubt his suggestion would be adopted.

Mr. le Maistre said he did not intend his suggestion to be an addition to the resolution, and far from mistrusting the International Executive he would willingly accept Dr. Smith's suggestion.

The resolution was then put to the meeting and declared carried *nem con.*

Prof. Carlo Padovani (Italy), speaking in French, said that in Italy there were only fuels of low grade and it had been extremely difficult to get accurate values for moisture content. The inert gas method was used, nitrogen free from oxygen being employed. He expressed the hope that the World Power Conference would be able to bring about standardisation of moisture tests, and added that the Italian Fuel Section would be only too pleased to put all their results at the disposal of the Conference to help forward the work of standardisation.

Mr. H. van Hettinge Tromp (Dutch East Indies) pointed out that no mention had been made of tests for determining the liability of coals to spontaneous combustion, but this was a very important matter in many cases. There had been many accidents due to spontaneous combustion, and in the Dutch East Indies twenty years ago spontaneous combustion was the topic of the day. No generally known method existed for determining the liability of coal to spontaneous combustion. There was the bromium absorbtion method, in which bromium was absorbed by the unsaturated compounds of the coal; but it was not altogether successful, and what was wanted was a method for the commercial man. The problem was studied in the Dutch East Indies eleven years ago, and the method devised by Dennstedt, Bunz und Schäfer, and described in the "Zeitschrift für Angew. Chemie," 1905 and 1912, was developed. This consisted of allowing a current of oxygen to pass through a U-tube with some very fine coal. The whole apparatus was immersed in a bath of oil and the rise of temperature was read off on a thermometer as the oxygen passed through the coal. In this way the spontaneous combustion temperature of some twenty different coals was worked out, and the danger graded by means of the "initial" temperature and "initial" curves determined.

The meeting closed with a cordial vote of thanks to the Chairman, Vice-Chairman, authors of papers and speakers in the discussion.

SECTION C

COAL TREATMENT
(a) CLEANING (b) DRYING
(c) BRIQUETTING

C1 CLEANING BITUMINOUS COAL.

C2 THE DRYING OF BROWN COAL WITHOUT BREAKAGE.

C3 THE DEWATERING AND DRYING OF COAL.

C4 THE CLEANING OF SMALL COAL.

C5 THE CLEANING OF COAL BY FROTH FLOTATION.

C6 THE PRINCIPLES OF PNEUMATIC SEPARATION, WITH A DESCRIPTION OF THE STATIC DRY WASHER.

C7 THE DRY CLEANING OF COAL.

THE NUMBERS ARE THOSE GIVEN TO EACH PAPER
FOR USE AT THE FUEL CONFERENCE

CLEANING BITUMINOUS COAL

AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS

J. R. CAMPBELL

Paper No. C1

CONTENTS

WASHABILITY STUDIES—SULPHUR IN COAL—METHODS OF WASHING COAL—METHODS OF DRYING—WASHING EFFICIENCIES—COST OF WASHING—RESULTS OF WASHING—BIBLIOGRAPHY—LIST OF EXPERTS—RÉSUMÉ

Washability Studies

The term washability of coal was coined when washing was the universal method of separating coal from its impurities by utilising their difference in specific gravity. This and analogous terms are still used in their broad sense, although pneumatic separation is now used to clean coal. These terms are so used in this paper.

Too much time or money can hardly be spent on feed surveys to get a picture of the coal that is to be cleaned. There have been too many rule of thumb methods used. Screen analyses and sink-and-float tests on the raw coal enable the coal operator and washery man to predict within reasonable limits the results that may be expected from any efficient cleaning apparatus.

The sizes to be examined to get the picture are optional to the investigator, but a good picture of the coal may be obtained by the following screen analysis:—

4 to 1½ in.; 1½ to ½ in.; ½ to $^5/_{16}$ in.; $^5/_{16}$ in. to 14 mesh*; 14 to 28 mesh; 28 to 48 mesh;

and for very complete data on the fines:—

48 to 100 mesh; 100 to 200 mesh; and through 200 mesh.

* Throughout this paper screen sizes are Tyler standard and are round-holed above 14 mesh, square-holed below 14 mesh. Tons are 2,000 lb.

Sink-and-float tests are made on all the fractions down to 48 mesh at the different gravities and a composite calculated. The minus 48 mesh is calculated into the cleaned coal results in its original state unless oil flotation is being considered as an adjunct.

The range of gravities used in testing is important and may start at 1.3 and end at 2.0. The lower gravity will show the inherent ash and sulphur in the coal and the higher gravity will determine the character of the rock end. A sufficient number of gravity fractions should be made to determine the character of the intermediates, especially the middling or bone product, which is very often the cause of much grief.

The washability of any given coal is directly determined by the washability curves thus set up. Interpretation of the curves is highly important. Sharp breaks in the curves tend to show a good washing proposition at the gravity where the break occurs, and the break shows a small proportion of tonnage within a wide gravity range. Another factor in the washability study, always well recognised, is the effect of crushing for liberating the impurities, especially in metallurgical coal.

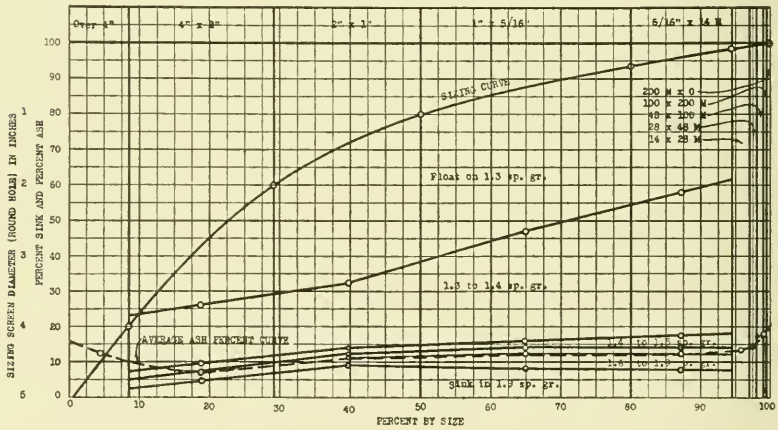


Fig. 1.

Test procedure.—The total sample is quartered so that it can be conveniently handled and is then sized over standard screens. The results of the sizing test are tabulated to show the screen analysis with the ash and sulphur content of the respective sizes (Fig. 1).

The results of the respective float-and-sink tests on each separate size are tabulated on the form accompanying each

washability curve (Fig. 2). The columns giving weight per cent. and ash or sulphur per cent. give direct test data. The cumulative weight and ash or sulphur per cent. columns, both float and sink, are obtained by the usual calculation of cumulatives.

Washability Curves.—The float-and-sink data with analyses are then plotted on the corresponding washability curve (Fig. 2) with ordinates and abscissæ as noted on this form. The curves then represent the following information, regarding either ash or sulphur, with an ash curve taken as an example.

TEST ON 4 in. MODIFIED, FROM ELKHORN SEAM, LETCHER COUNTY, KY.

Sampling and Peculiarities of Sample:
Coal is fairly hard and tends to break in blocks. The rock is grayish, conchoidal and fairly hard.

General data.	Sizing tests.	Wt. lb.	Wt. per cent.	Ash per cent.	Sulphur per cent.	Wt. per cent. of sample
Total weight of sample: 663 lb.	Over 4 in.	55·75	8·41	12·10		8·41
	4 to 2 in.	138·00	20·82	7·24		20·82
Volatile matter, per cent.: 36·5*	2 in. to 0	469·31	70·77	11·64		
	Total and average	663·06	100·00	10·76		
*On 1·3 to 1·4 sp. gr. fraction of $^{5}/_{16}$ in. to 14 mesh size.	2 to 1 in.	36·625	29·42	11·16		20·84
	1 to $^{5}/_{16}$ in.	52·750	42·36	11·81		29·99
	$^{6}/_{16}$ in. to 0	35·125	28·22	11·85		
	Total and average	124·500	100·00	11·64		
	Through $^{5}/_{16}$ in. Over 14 mesh**	Gms. 1399	71·84	10·70		14·32
	Through 14 mesh** over 28 mesh	230	11·82	13·20		2·36
	Through 28 mesh over 48	137	7·04	13·90		1·41
	Through 48 mesh over 100 mesh	90	4·63			0·92
	Through 100 mesh over 200 mesh	45	2·31	17·40		0·46
	Through 200 mesh	46	2·36			0·47
**14 mesh is eqivalent to $^{1}/_{16}$ in. round hole screen.	Total and average	1947	100·00	11·85		
	Grand total and average			10·76		100·00

Curve 1, which is the cumulative float ash per cent. curve, represents the variation of ash per cent. according to the recovery.

Curve 2 represents the variation in ash per cent. of the material with variation in gravity at which separation is made.

Curve 3 represents the cumulative sink ash per cent. according to the same recovery as Curve 1.

Curve 4 represents the variation of recovery according to specific gravity.

Separate curves may be made for each size, but it is unnecessary to show such curves in detail, for they have often been shown and described elsewhere. As an example, a composite curve (Fig. 2), for an Elkborn, Kentucky coal from 4 to $^{5}/_{16}$ in. is shown, which gives a picture of what may be accomplished in the way of ash reduction and recovery. The sharp breaks in the curves show where economical washing should be done. With a recovery of about 90 per cent. the raw coal is reduced from 10.31 per cent. ash to below 4 per cent. ash in the washed coal. The rock end or refuse shows about 62 per cent. ash. The necessary tests were made by the American Rheolaveur Corporation.

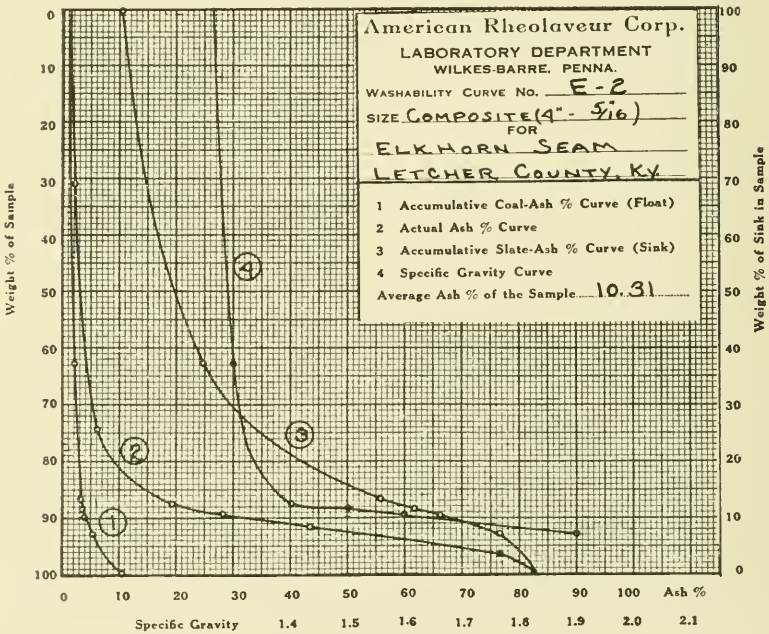


Fig. 2.

Other curves might have been shown if space permitted, to show how the preliminary survey by constructing washability curves indicates that fine crushing would improve the washing. Similarly, the possibility of sulphur reduction can be found by making the curves, but substituting sulphur for ash content.

We have been criticised sometimes for "washing coal on paper with curves" instead of in practical test plants. The author has made many practical tests and has found that practical tests do not always bring out all the facts on the washability of a given coal, and often lead to wrong conclusions; therefore, he prefers to "wash on paper" first and then see if the washing equipment measures up to the standard. The theory must precede the practice.

FLOAT AND SINK TESTS ON 4 in. MODIFIED FROM ELKHORN SEAM, LETCHER COUNTY, KY.

ASH RESULTS

Size: Composite 4— $\frac{5}{16}$ in. Curve No. E-2

Specific Gravity	Weight per cent.	Ash per cent.	CUMULATIVE FLOAT Weight per cent.	CUMULATIVE FLOAT Ash per cent.	CUMULATIVE SINK Weight per cent.	CUMULATIVE SINK Ash per cent.
>1·30	63·68	2·04	63·68	2·0	100·00	10·31
1·30—1·40	22·65	6·10	86·33	3·1	36·32	24·80
1·40—1·50	1·90	19·27	88·23	3·5	13·67	55·80
1·50—1·60	1·30	28·00	89·53	3·7	11·77	61·80
1·60—1·90	3·32	43·40	92·85	5·2	10·47	66·00
>1·90	7·15	76·40	100·00	10·31	7·15	76·40
Total	100·00					
Average		10·31				
Used to plot curve No. 00	4	2	1, 2*& 4	1	3	3

Curve 2 (Fig. 2) is an important factor in determining the washability of any coal. If it flattens out fairly well, the coal will wash easily, but if it comes down rather straight, the washery will have trouble. This curve indicates the material which, based on the law of probability, will sink or float at definite gravities. It might be called the material in the "twilight zone," or the "teeter column." In other words, Curve 2 shows the character of the heaviest particle of material that will remain in the washed coal

*The ordinates are the means of successive pairs of float, the first ordinate being the mean of first weight and zero.

or the lightest that will go to the refuse at the various washing gravities or recoveries.

Sulphur in Coal

The forms of sulphur in coal are generally recognised as organic, pyritic and sulphate. Simmersbach was an early investigator of these forms. Parr and Powell have made valuable contributions to the literature on the subject. Recently, industrial chemists and engineers, like Russell, of the Youngstown Sheet and Tube Co., and Morrow, of the Pittsburgh Coal Co., have gone into the practical aspects as applied to coal washing.

Morrow[1] has set up some data tending to show that there is, in some cases, a concentration of organic sulphur in the middlings which makes it susceptible of removal in washing. This is contrary to the old idea that organic sulphur is not removed by washing.

Pyritic sulphur is in the form of iron sulphide, pyrite or marcasite (FeS_2). The decomposition, or weathering, of sulphur balls seems to indicate that marcasite is more prevalent than pyrite. This has some bearing in coal washing, in making the circulating, or wash water, acid in character; however, it is a way of sulphur removal by the wet process and may partly account for the use of a factor in determining the practical sulphur results from sink-and-float data.

Formerly, it was believed the FeS_2 was changed to Fe_7S_8, a magnetic sulphide, during the coking process, which eliminated about 43 per cent. of the sulphur. The fact that the sulphur balls found in coal become highly magnetic when put through the coking process probably led the early investigators to this conclusion. Now Dr. A. R. Powell[2] writes positively that straight FeS is formed during the coking process, with a deposition of solid sulphur, which makes the new compound magnetic.

Sulphate sulphur is in the form of calcium sulphate and iron sulphate, the latter being caused by oxidation. The percentage is invariably small. Organic sulphur contains both humus and resinic sulphur; the resinic ranges from 25 to 40 per cent., the humus from 75 to 60 per cent.

The forms of sulphur in the coal apparently have little effect on the percentage burned out during by-product coking. The organic and pyritic sulphur seem to behave much alike. The percentage of sulphur volatilised varies from 35 to 45 per cent. from a

practical standpoint, depending on conditions. Thus, we may reasonably expect the sulphur in the coke to be a few points lower than in the raw coal. This ratio is dependent somewhat on the volatile matter in the coal and the consequent coke yield.

Table I gives forms and distribution of sulphur in the Pittsburgh, or No. 8, seam of coal in the Pittsburgh district, Pennsylvania.

TABLE I.—FORMS AND DISTRIBUTION OF SULPHUR IN THE PITTSBURG SEAM

Mine	A per cent.	B per cent.	C per cent.	D per cent.	E per cent.	F per cent.	G per cent.
Organic Sulphur ...	0·64	0·59	0·56	0·62	0·64	0·71	0·65
,, Pyritic ...	1·26	0·38	1·26	0·36	0·46	1·39	0·74
,, Sulphate	0·02	0·02	0·02	0·02	0·02	0·02	0·02
Total ...	1·92	0·99	1·84	1·00	1·12	2·13	1 41

Methods of Washing Coal

The principle underlying the separation of impurities from coal in all important processes is the difference between the specific gravities of coal and refuse.[3] There are two very active schools for cleaning bituminous coals in America, pneumatic (or dry cleaning) and wet washing, with water.[4] Very lately there has sprung up a compromise school, advocating a duel process. The author mentioned the possibilities of a dual system as early as 1919.

Figs. 3 and 4 are simple flow sheets of a complete wet-washing plant and a typical dry-cleaning plant. In Fig. 4, Y=full-Wye; HY=half-Wye; YA=split-Wye.

Forbes[5] gives the following advantages of the two systems:—

"For water flotation—ability to treat greater variation in size, in other words, to treat as small size as, and larger size coal than air flotation; ability to treat coal in greater range of sizes in one operation, resulting in less screening required."

"For air flotation—avoidance of added expense on account of added moisture either for transportation of the extra weight, or for evaporation in use."

He then gives an example of wet washing, "where, in order to secure as low ash as possible in the coking coal, the bone or intermediate coal was also removed in the washing and used for boiler purposes." In concluding, he says, "that all of the treating processes will provide a more uniform product by reducing the

ash and sulphur content, and that a combination of the wet and dry systems would give better results on some coals than either all wet or all dry processes on the same coals. Therefore each installation must be considered separately, and the best process selected to obtain the results desired, considering at the same time the added installation and operating costs."

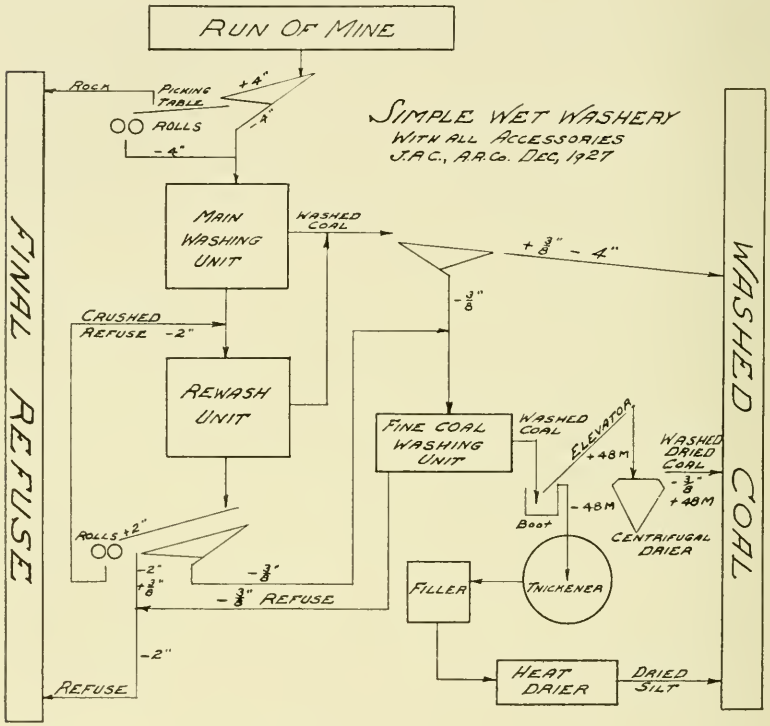


Fig. 3.

Rheolaveur.—The latest development of the launder washer is the Rheolaveur (current washer), which embodies the features of simplified rewashes, refuse draw-offs and a regulating product (or fly wheel), all of which makes it efficient with high capacity. On larger sizes, $3\frac{1}{2}$ to $^{3}/_{64}$ in., a going plant shows 150 to 200 tons per hour on a 32-in. launder. On fine sizes, $^{5}/_{16}$ to 0 in., the rated capacity is 50 to 60 tons per hour. A complete plant under construction in the Pittsburgh district for bituminous coal has a rated capacity of 500 tons per hour on two 48-in. primary launders.

Jigs.—Two types of jigs have carried the burden of bituminous coal washing in America for a good many years; the basket type and the overflow type. The overflow type may be either single or

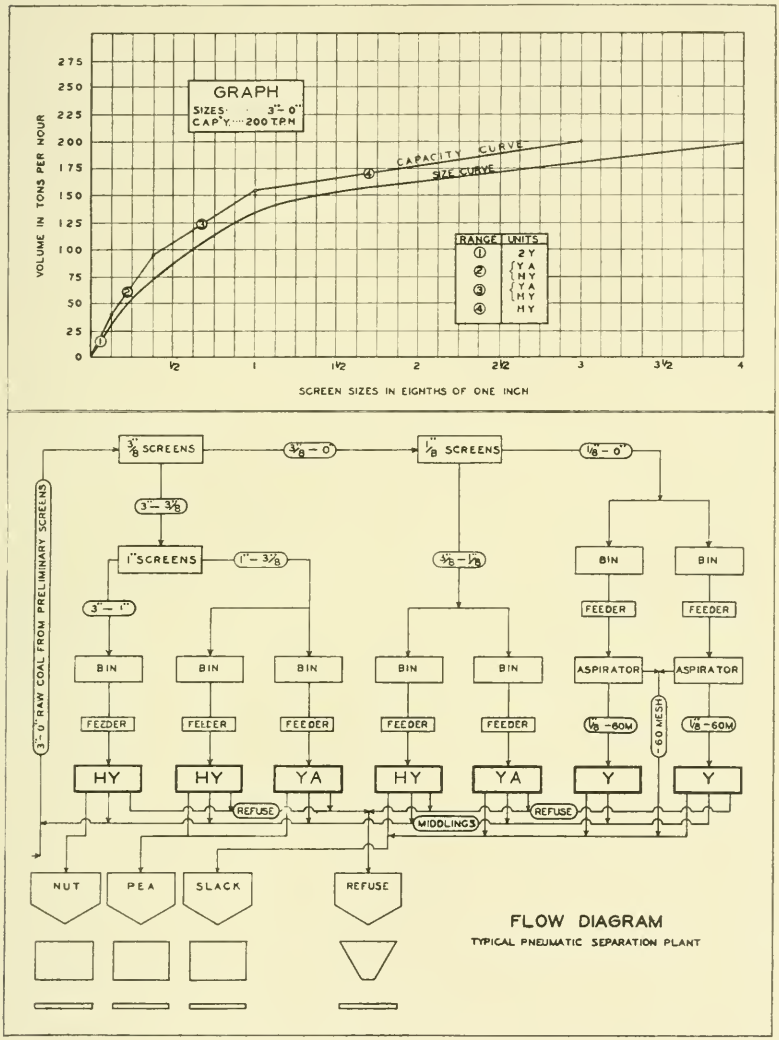


Fig. 4.

multiple compartment, and makes its own bed or has an artificial bed of feldspar.

Concentrating Tables.—Jigging fine coal presents some difficulties and for that reason considerable attention in late years has been

given to wet concentrating tables for handling fines. The principal tables are the Campbell bumping table, the Overstrom table, the Deister-Overstrom table and the Deister Machine "Plato" table. The chief difficulty of the wet tables is their low capacity on fines, varying from 5 to 10 tons per hour.

Bird and Yancey[6] propose to increase both the capacity and efficiency of wet tables by classifying the feed hydraulically instead of mechanically by screens. This is a step in the right direction, and it will be interesting to follow the commercial developments and see what this step adds to the cost of tabling.

The wet table is sometimes used as an auxiliary to a jig plant where the fines have to be treated, and the combination makes a good dual plant. Wet tables may also be used as complete installations where fine crushing is necessary.

Tubs and Cones.—The Robinson-Ramsay tub exemplifies the tub method of cleaning coal. The Chance cone uses a fluid mass of sand and water as the flotation medium. So far as known, there is only one installation on bituminous coal. The fines are by-passed the cone, which is similar to anthracite practice. Paul Sterling tells something about this and other cleaning devices used in the anthracite region.[7]

Hydraulic Classifiers.—Recently the Menzies Hydro-Separator has made its appearance in bituminous practice, especially in Southern West Virginia. It was originally a development in the anthracite district of Pennsylvania, where it is used on steam sizes. The sponsors for the machine in bituminous practice claim that it will handle all sizes from egg to slack with a capacity of 25 to 40 tons per hour. The egg size is up to 4 or 5 in., which, it is claimed, would eliminate hand-picking.

The Dorr machines are valuable adjuncts in wet washing.

Dry Cleaning.—The accepted methods of dry cleaning are hand picking, mechanical pickers and spirals, Bradford breakers and dry tables. We will concern ourselves only with dry tables.

The author's first experience with dry tables was in Dubuque, Iowa, about 1914, where W. W. Bonson had the first dry coal tables. Later, the author spent considerable time at the parent plant of Sutton, Steele & Steele, in Dallas, Texas. The American Coal Cleaning Corporation, Welch, W. Va., later acquired the rights to use the Sutton patents, and built the third dry plant in the country at McComas, W. Va., for the American Coal Co., under the direction of a large construction company.

The Wye table has been developed by the parent company. Close pre-sizing is needed to obtain the best results. The rated capacity of the Wye table is as follows :—

Size, in.	Tons per hour.
3–1	70
1–$\frac{3}{8}$	50
$\frac{3}{8}$–$\frac{1}{8}$	35
$\frac{1}{8}$–0	20

Dry tables have also been devised and plants built by Roberts and Schaeffer Co., Chicago, Ill., Heyl & Patterson, Inc., Pittsburgh, Pa., Peale, Peacock & Kerr, St. Benedict, Pa.

Dry cleaning has many logical applications, but after close observation of going plants, the author is satisfied that a modern, well-regulated wet-washing job has a higher efficiency than a dry-table job, and for that reason wet washing must be used in difficult metallurgical operations where sulphur is the important factor.

Methods of Drying

As Forbes[5] points out, the sole advantage of dry cleaning is "avoidance of added expense on account of added moisture, either for transportation of the extra weight, or for evaporation in use." In view of this, attention is being given to drying the coal from wet washing. Washed coal is de-watered by various methods, the principal ones being: de-watering elevators and screens, drainage bins and pits, centrifugal dryers, filters and presses, and direct heat dryers.

The general scheme is: (*a*) to de-water the top sizes above $\frac{1}{2}$ in. or $\frac{5}{8}$ in. by natural drainage; (*b*) centrifugally dry the $\frac{5}{8}$ in. to 48 mesh and (*c*) dry the slimes (48 mesh to 0) by heat, and thus obtain a wet-washed coal that is sufficiently dry for all ordinary uses.

Centrifugal dryers have been in use for several years. The latest development is the Carpenter dryer, used by the Colorado Fuel and Iron Co. This dryer has a rated capacity of 75 tons per hour, and will reduce the moisture to 5 or 5.5 per cent. if the fines are not excessive. The cost is not high (about $0.025 per ton) and is distributed as follows: depreciation (10 per cent.) $0.007; power $0.010; maintenance $0.008.

Heat drying of the sludge, or slimes, 48 mesh to 0, is a new development in the art, and operating data are not available at present. The operating cost is estimated at from 5 to 8 cents. per ton, depending upon the character of the fuel used, which in most

cases may be a secondary coal recoverable from the refuse, but since the tonnage is small (usually not over 5 per cent. of the feed coal) the net cost is low.

A bituminous wet-washing plant now under construction in the Pittsburgh district will develop all the above methods of drying.

It is the feeling among coke-oven men that the extra heat required to evaporate moisture is not so important. This must be, in view of the facts. To evaporate 1 lb. of water from and at 60°F. required about 1,100 B.Th.U. To superheat the steam to stand pipe temperature raises this to about 2,500 B.Th.U. About 1,200 B.Th.U. are needed to coke 1 lb. of average coal in a by-product oven; 1 per cent. of moisture would require about 25 B.Th.U.; 1 per cent. of moisture would replace 1 per cent. coal (requiring about 12 B.Th.U.), so that the net change in heat requirements would be only 13 B.Th.U.

What coke-oven men do object to is coal dripping wet, on the grounds of reduced oven capacity and possible effect on coke structure; objections which can largely be removed by modern methods of drying wet-washed coal. In certain other cases, good by-product practice demands a coal containing moisture, and sometimes water has to be added. For instance, swelling coals, which cause stickers and a deposit of carbon, demand a moisture content of 5 to 6 per cent.

Sludge Recovery and Water Clarification.—The recovery of slimes is not the bugaboo it once was. Fines in water can be definitely collected by means of Dorr thickeners and filters and then heat-dried. The underflow containing a fifty-fifty mixture of solids and water can be further dehydrated by filters to 15 to 20 moisture and the cake sent to direct heat dryers. The water is clarified for re-use.[8]

Dust Recovery.—Dust recovery presents a more difficult problem. The methods employed are (*a*) cyclone dust collectors, and (*b*) baghouse collectors. In going dry-table plants in the Pittsburgh and West Virginia districts equipped with cyclone dust collectors, the dust problem has not been completely solved. It is comparatively easy to get the dust out of the plant, but it goes elsewhere, and in some cases becomes a nuisance to the inhabitants of the mining camp and to the farmers.

The American Coal Cleaning Corporation, Welch, W. Va., has taken a long step to mitigate this evil by the use of baghouse dust collectors. This system is more expensive than cyclone

dust collectors—about double the cost—but at the plant thus equipped at Berwind, W. Va., little or no dust was escaping through the bags.

Washing Efficiencies

One of the most important parts of a washing job is to determine the efficiency. We start the picture with a washability study of the coal to be cleaned, based on sink-and-float tests; therefore, we must logically end as we began.

Efficiency of washing based on sink-and-float test is determined by Drakeley's formulæ, which are as follow:—

$$\text{Qualitative Efficiency} = 100 \times \frac{\text{Washed coal float—feed coal float}}{\text{100—feed coal float}}$$

$$\text{Quantitative Efficiency} = 100 \times \frac{\text{Feed coal float} - \frac{\text{Per cent. refuse} \times \text{refuse float}}{100}}{\text{Feed coal float}}$$

Using the following figures:

	Ash per cent	Float 1·95 Sp. Gr. per cent.
Feed coal (100)	16·12	90·00
Washed coal (88·4 per cent.)	7·68	98·76
Refuse (11·6 per cent.)...	80·20	1·76

$$\text{Qualitative Efficiency} = \frac{100(98{\cdot}76 - 90{\cdot}00)}{100 - 90} = 87{\cdot}6 \text{ per cent.}$$

$$\text{Quantitative Efficiency} = 100 \times \frac{90 - \frac{11{\cdot}63 \times 1{\cdot}76}{100}}{90{\cdot}0} = 99{\cdot}76 \text{ per cent.}$$

A rough approximation of the quantitative efficiency is to multiply the percentage of reject by the percentage of good coal in it and subtract the product from 100. A good many practical men simply use the multiplicaton and call the product "loss of feed coal" or "bank loss." This, perhaps, is the practical way of arriving at the cost of bank loss.

A standard of 85 per cent. for qualitative efficiency and 99.5 per cent. for quantitative efficiency, if the total reject is not excessive, is not too high.

For plant control, the author uses the Delatester (Fig. 5) because it is a standard machine for making sink-and-float tests in the plant or laboratory. After a sufficient number of these tests have been made to determine the character of the products produced by the washer, chemical analyses may be relied upon to give sufficient control.

Only one gravity should be used in testing, and that is the gravity of washing. Some investigators use one gravity for washed coal and a lower gravity for testing the refuse. This practice is misleading and leads to wrong conclusions. It would be permissible

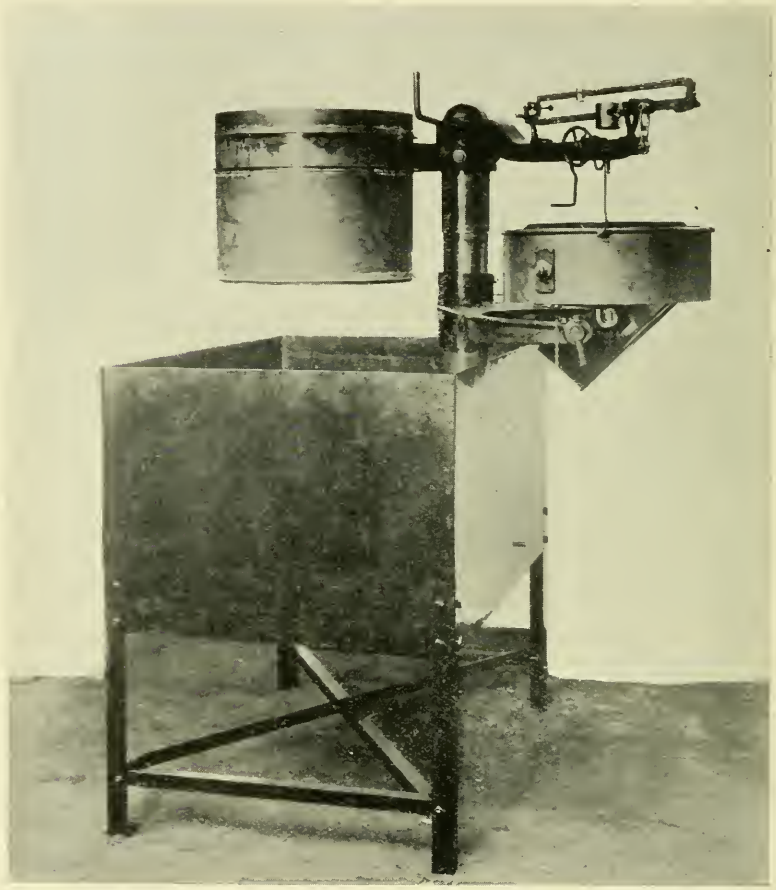


Fig. 5.

where there is a considerable percentage of middlings near the washing gravity. For example, if the washing gravity is 1.50 and there is considerable material between 1.40 and 1.60, a better picture of the washing results could perhaps be obtained by testing the washed coal and refuse at 1.40 and 1.60 instead of at the washing gravity of 1.50. Where a dual gravity is used,

the results should be converted to a single gravity, that of washing operation, before attempting to calculate efficiencies.

Fig. 6 shows a convenient form for keeping sink-and-float data.

CHEMICAL TEST DATA
ON
_____WASHERY

Qualitative Efficiency = _____per cent. ASH Quantitative Efficiency = ___Per Cent

	FEED COAL				WASHED COAL				REFUSE				TONNAGE		PER CENT REFUSE			
Date	Ash in Float	Ash in Sink	Comp. Ash	Per Cent Sink	Ash in Float	Ash in Sink	Comp.	Per Cent Sink	Ash in Float	Ash in Sink	Comp. Ash	Per Cent Sink	Coal	Refuse	By Wts.	By Calcn.	Hrs.	*Sp. Gr.
Ave..																		
Cum. Ave.																		

* Washing gravity and testing gravity must be the same

REMARKS

Fig. 6.

Cost of Washing

The cost of washing may be divided into capital cost and operating cost.

The capital cost of any cleaning or preparation plant is dependent entirely upon conditions and the work demanded of it. Judging from the data at hand, an efficient wet-washing plant, complete with all accessories and housing, will cost from $400 to $800 per ton per hour. It is the common belief among operators that complete dry-table installations are considerably higher in first cost. Perhaps it will be fair to say that the air-table plant can be built for from $500 to $1,000 per ton per hour, complete with all accessories and housing.

The operating cost may be conveniently sub-divided into labour, power, maintenance, depreciation (and interest), loss of input, or "conversion cost."

Conversion cost is considerably more important than many are willing to understand. For example, 100 tons of run-of-mine coal costing $1.80 per ton is delivered to the cleaning plant. In going through the preparation plant there is a shrinkage of 10 tons, therefore, there are only 90 tons of market coal that cost $180, or $2 per ton. In this case, the conversion cost is 20 c.

per ton—a very large item in figuring the costs. It is more unfortunate if the 10 per cent. loss of input should contain a bank loss of 2 or 3 per cent. of good market coal. The sure way to get real money for coal is to get it into the railroad cars for market—not into the little refuse dump car that puts it where it is irretrievably lost. Bank loss is no misnomer, and is a real factor in washing costs.

Continuing on a percentage basis, the problem may be set up as follows :—

90 per cent.=$1.80.
1 per cent.=$0.02.
3 per cent.=$0.06 (based on 30 per cent. coal in refuse).
7 per cent.=$0.14 (based on 70 per cent. rock in refuse)

Thus the 20 c. loss of input cost may be divided into 14 c. for real rock or slate with no value and 6 c. for good coal with a potential value of the full amount, at least, if shipped to market. Bank loss should be figured at more than the cost value, for if sold at a profit, the washing costs would be reduced. The anthracite operator probably is nearer right when he figures his bank loss at the sales value.

In the matter of the total cost of washing, the tendency on the part of many manufacturers is to oversell their equipment on this point. Coal cannot be washed for nothing, or near nothing, as many figure it. The splendid work of estimating engineers is a safeguard in this respect. The following are good average figures.

COST OF WASHING PER TON (500 tons per hour capacity)

	Cents.
1. Building upkeep	0·25
2. Machinery upkeep	1·40
3. Labour	3·00
4. Power	2·25
5. General overhead	1·70
6. Supplies	0·30
	8·90

These figures do not include depreciation and interest, which may add another cent. or two; or conversion cost, which is considerable in some cases if there is excessive bank loss. Under ordinary conditions, coal can be washed in modern and efficient equipment for from 20 to 25 c. per ton including all items of cost.

The cost of washing can be predetermined very accurately from the known factors in the washing problem—the washability study and engineering data.

Results of Washing

Forbes[5] shows some washing results which are undoubtedly based on washing the Pratt seam of coal in Alabama in a modified Elmore compartment jig. The figures of Table II are quoted from his paper.

As is well known in the south, this concern produces three products: washed coal, boiler coal, and refuse. It will be noted that the secondary coal or middlings has practically the same fuel value as the raw coal. The coal losses are concentrated in the middling product, which makes the refuse clean. The production of a secondary coal is not always permissible, especially where there is no particular use for it, and for this reason we cannot always build washers on such a basis.

TABLE II.—DATA OF WASHING RESULTS

Washer	RAW COAL				WASHED COAL			
	Volatile matter	Fixed carbon	Ash	Sulphur	Volatile matter	Fixed carbon	Ash	Sulphur
No. 1 ...	27·48	56·85	15·67	1·44	30·79	65·29	3·92	1·09
No. 2 ...	27·61	62·25	10·14	1·43	29·13	66·23	4·64	1·17
No. 3 ...	26·51	60·93	12·56	1·59	28·67	66·72	4·61	1·22
No. 4 ...	25·34	61·46	13·20	1·86	27·77	67·71	4·52	1·28

Washer	BOILER COAL				REFUSE					
					Float at 1·37			Sink at 1·37		
	Volatile matter	Fixed carbon	Ash	Sulphur	Per cent.	Ash	Sulphur	Per cent.	Ash	Sulphur
No. 1 ...	27·64	59·31	13·05	1·62	3·9	3·85	1·10	96·1	70·62	2·14
No. 2 ...	26·00	59·80	14·20	2·00	4·2	4·79	1·27	95·8	61·83	4·67
No. 3 ...	26·05	60·85	13·10	2·03	4·9	4·92	1·35	95·1	63·33	4·08
No. 4 ...	25·12	61·20	13·68	2·20	4·7	4·70	1·48	95·3	56·00	5·24

TABLE III.—RESULTS WITH VARIOUS METHODS AND METALLURGICAL COALS

	TABLE PLANT "A"		TABLE PLANT "B"		JIG AND TABLE PLANT "A"		JIG AND TABLE PLANT "B"	
	Ash per cent.	Sulphur per cent.	Ash per cent.	Sulphur per cent.	Ash per cent.	Sulphur per cent.	Ash per cent.	Sulphur per cent.
Feed coal ...	13·00	2 50	11·00	2.00	12·00	2·80	9·80	1·66
Washed coal	8·80	1·30	6·50	0·90	8·20	2·00	8·20	1·37
Refuse ...	47·00	12·20	29·60	4·56	45·00	11·11	43·40	7·90
Reject, per cent. ...	11·00		20.00		9·00		4·5	
Seam of coal	Kitta nnings		Free port.		Illinois	No. 6	Pittsbur gh No. 8	

The tabulation also indicates that the float in the refuse is apparently made on the dual basis, to which there is serious objection from a technical standpoint. The float is made at 1.37, whereas the washing gravity undoubtedly is considerably higher.

Table III shows some results from plants covering the other types of apparatus mentioned in this paper, all based on metallurgical coal.

The results on the Rheolaveur washer (Table IV) on metallurgical coal are shown somewhat more in detail, since such figures are available. The figures are taken from Spahr.[9] A screen analysis

TABLE IV.—RESULTS WITH RHEOLAVEUR WASHER ON METALLURGICAL COAL

Retained on	Weight, per cent.	Cum. weight, per cent.	Ash, per cent
$\frac{5}{16}$-in.	0·7	0·7	33·7
$\frac{1}{8}$-in.	23·3	24·0	23·2
$\frac{1}{16}$-in.	39·2	63·2	15·5
48 mesh	25·4	88·6	17·0
100 mesh	6·0	94·6	18·8
200 mesh	2·6	97·2	20·0
Through 200 mesh	2·8	100·0	18·1

1927	Figured recovery per cent.	WASHED COAL ASH		REFUSE ASH		Actual recovery per cent.
		Actual per cent.	Theoretical per cent.	Actual per cent.	Theoretical per cent.	
Jan. 12 to 31	82·1	10·20	9·0	48·10	51·1	
Feb. 1 to 15	82·6	10·10	9·1	49·70	51·9	
Feb. 16 to 28	83·2	10·15	9·4	51·20	53·0	
Mar. 1 to 31	83·2	10·17	9·4	50·83	53·0	81·8
July 1 to 31	82·0	10·30	9·8	49·20	51·0	82·6

of the washed coal shows that the 14 mesh to 48 mesh material is washed practically as well as the larger sizes. These results are somewhat different from other gravity methods.

It has not been possible to obtain extensive figures from dry-cleaning plants. The results shown in Table V are from a going plant and were taken throughout the entire day of August 11, 1927. It is the intention of this plant to recover, in the domestic sizes, the bone coal which has been crushed from the pickings of the lump and egg sizes.

No data have been given on bank loss. The analyses of the refuse will give some indication of this loss to the reader who is acquainted with the characteristics of the coal and who knows

what the ash in the refuse ought to be at the washing gravity. There is, perhaps, a wide range of bank loss—anywhere from 5 per cent. of float coal in refuse from the best performance to 40 per cent. of float in refuse from the worst performance. In some cases not listed here, washery wastes have shown 30 to 40 per cent. float coal at the washing gravity.

TABLE V.—DATA OF ONE DAY'S RUN FROM DRY-CLEANING PLANT

Coal	Size, in.	Clean Coal. Domestic Size, Bone left in . Ash, per cent.
Nut	2-1	9·15
Pea	1-½	7·26
Slack	½-¼	6·62
	¼-⅛	6·23
	⅛-0	7·21

	Ash, per cent.
Average 2 to 0 in. clean coal with bone left in, and pea size	7·21
Average 1 to 0 in. clean coal with bone left in, 1 to ½ in. size	7·08
Average ½ to 0 in. slack	7·07
Theoretical ash in coal	5·50
Theoretical ash in refuse	86·00
Refuse, 6 per cent. of whole	80·00

Crude 2 to 0 in. without middlings, but with all bone pickings of sizes over 2 in. crushed through 2-in. single roll crusher and added 10·98 per cent. ash.

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RÉSUMÉ

L'auteur met en lumière les points fondamentaux suivants, dans la préparation mécanique des charbons bitumineux:

1. La nécessité d'études de "lavabilité."
2. Le type d'installation correspondant au charbon étudié.
3. Le contrôle de la marche de l'installation.
4. Le prix de revient du lavage—tous les facteurs.

Sous le titre 1, l'auteur dit: Trop de temps ou d'argent pourrait difficilement être employé pour obtenir une représentation ou une "image" du brut à nettoyer. Trop de methodes empiriques ont été en usage. La décomposition en grosseur (essais de tamisage) et la séparation à diverses densités (essais de flottants et déposés) du charbon brut permet au charbonnier de même qu'au laveur de prédire, dans certaines limites, les résultats auxquels on peut s'attendre de tout appareil efficace de préparation.

L'auteur s'occupe dans une partie de la première moitié du mémoire des résultats d'une série d'études de lavabilité faites sur un charbon américain.

Sous le titre 2, il discute les méthodes de lavage employées aux Etats-Unis, et met en lumière l'importance du choix du type d'installation qui se prête le mieux aux conditions du problème du lavage. Les méthodes modernes de

séchage du charbon lavé, la récupération des schlamms et la clarification des eaux de lavage sont discutées en détail et un croquis d'ensemble est donné, montrant clairement une installation type. L'auteur décrit alors les progrès récents dans l'art du séchage des charbons lavés à l'eau et le traitement des schlamms, parce qu'il croit que le lavage par voie humide est le seul moyen logique de traiter les problèmes de lavage, difficiles, quand le charbon doit être employé pour des usages métallurgiques et que le problème du soufre est le problème immédiat, ce qui est le cas d'un grand nombre de charbons aux Etats-Unis.

Sous le titre 3, l'auteur montre l'importance qu'il y a de mesurer exactement la marche d'un lavoir à charbon; il montre une méthode standard de tenir compte d'essais de flottants et déposés, obtenus au moyen du Delatester. Il fait remarquer la nécessite d'exprimer les résultats par des formules de rendement établies.

Sous le titre 4, l'auteur discute les facteurs entrant dans le prix de revient du lavage, soit:

Les frais d'exploitation qui peuvent d'une manière convenable être subdivisés en main-d'oeuvre, puissance motrice, entretien, dépréciation (et interêt); perte à l'entrée ou frais de "conversion."

Les frais de conversion sont bien plus importants que beaucoup ne veulent le croire. Par exemple, 100 tonnes de charbon tout venant, coûtant $1.80 à la tonne, sont débitées à l'installation de préparation. En passant par l'installation de préparation, cette quantité subit une diminution de 10 pour cent, par conséquent il ne reste que 90 tonnes de charbon à vendre qui coûtent $180, soit $2 la tonne. Dans ce cas, les frais de conversion entrent pour 20 cents à la tonne ce qui est un facteur très important dans le prix de revient. Il est plus défavorable encore si, dans ces 10 pour cent de perte à l'entrée, entrent 2 à 3 pour cent de perte au terril en bon charbon. Le moyen certain d'obtenir de l'argent comptant pour du charbon est de le charger dans des wagons pour la vente,—et non dans le petit wagonnet allant au terril qui le transporte là où il sera irrémédiablement perdu. "Perte au terril" n'est pas une mauvaise dénomination et est un réel facteur dans le prix de revient de lavage.

Les résultats de lavage dans des installations des Etats-Unis d'Amérique terminent le memoire.

DIE TROCKNUNG WASSERREICHER BRAUNKOHLE UNTER BEIBEHALT IHRER STÜCKFORM

(THE DRYING OF BROWN COAL WITHOUT BREAKAGE)

AUSTRIAN NATIONAL COMMITTEE, WORLD POWER CONFERENCE

PROF. DR. H. FLEISSNER

Paper No. C2

CONTENTS

A METHOD OF DRYING BROWN COAL WITHOUT BREAKAGE—
UTILISATION OF THE FUEL
ENGLISH VERSION (ABRIDGED)

Viele wasserreiche Braunkohlen, die von Natur aus sehr fest sind und in stückiger Form gewonnen werden können, zerfallen beim Trocknen. Diese Eigenschaft, die mit der Natur der Braunkohle und mit dem Fortschreiten des Trocknungsvorganges von aussen nach innen im Zusammenhange steht, ist in zahlreichen Fallen das Hindernis, die Trocknung zur Wertverbesserung dieser verhältnismässig häufig vorkommenden Brennstoffe anzuwenden; denn in den meisten Fällen sinkt der Wert mit der Verringerung der Korngrösse sehr beträchtlich.

In Oesterreich gibt es grosse Lignitvorkommen, deren Ausbeutung für die Zukunft nur dann Aussicht auf wirtschaftlichen Erfolg hat, wenn eine Wertverbesserung durch Verringerung des Wassergehaltes von ursprünglich 35-45% auf 13-15% erfolgen kann, womit eine Heizwertsteigerung von etwa 3 600 auf 5 000-5 100 Cal verbunden ist. Alle Bemühungen, eine solche Trocknung vorzunehmen, scheiterten jedoch bis vor kurzem an dem früher erwähnten Umstande, dass die Kohlen dabei weitgehend zerfallen. Erst nach Ausarbeitung eines besonderen Verfahrens konnte die Trocknung unter Beibehalt der Stückform der Kohle durchgeführt werden. Es sei mir nun gestattet, hier kurz das Wesen des Verfahrens zu

erläutern und hierauf über den gegenwärtigen Stand der Braunkohlentrocknung in Oesterreich zu berichten, da das Verfahren zweifellos auch für die Ausbeutung verschiedener anderer Lignitvorkommen von Bedeutung sein dürfte. Ueber die Vorgänge, die beim Trocknen der Braunkohlen infolge ihrer teilweise kolloiden Beschaffenheit zu beachten sind, und deren Erkenntnis schliesslich zur Durchbildung des früher erwähnten Verfahrens führte, wurde schon wiederholt von mir an anderer Stelle[1] berichtet, wobei auch eingehendere Angaben über das Verfahren selbst gemacht wurden.

Das Verfahren beruht im Wesen darauf, dass die Kohle zunächst auf höhere Temperaturen gebracht wird, ohne dass dabei Wasser verdampfen könnte. Die Wasserverdampfung darf erst dann einsetzen, wenn die Kohle bis ins Innerste auf die entsprechende Temperatur erhitzt worden war, so dass das hierauf folgende Trocknen von innen nach aussen erfolgt. Einen ähnlichen Vorgang hat man bekanntlich früher schon beim Trocknen von Formstücken in der keramischen Industrie angewendet, um deren Zerreissen und Verziehen zu vermeiden. Bei den Braunkohlen kommt man jedoch nur dann zum Ziele, wenn man die Erwärmung bis auf solche Temperaturen vornimmt, bei denen die in der Kohle vorhandenen kolloidartigen Stoffe bereits zum Gerinnen kommen. Diese Erwärmung geschieht zweckmässig in geschlossenen Behältern durch direktes Einleiten von Wasserdampf unter Druck. Der Wasserdampf muss gesättigt sein, damit der früher erwähnten Massnahme des Erhitzens ohne Wasserverdampfung entsprochen werden kann. Die Dämpfung der Kohle muss einige Zeit hindurch andauern, wobei ein Zusammenschrumpfen der einzelnen Kohlenstücke eintritt, dann erfolgt eine Entspannung des unter Druck befindlichen Behälters und schliesslich das eigentliche Trocknen durch ständige Herabsetzung des Wasserdampfteildruckes über der Kohle. Durch Anwendung der hier erwähnten Massnahmen lässt sich die Trocknung unter Aufrechterhaltung der Stückform durchführen.

Die anfänglich im kleinen Masstabe mit Hilfe eines Autoklaven durchgeführten Versuche brachten solche Erfolge, dass sich die *Oesterreichisch-Alpine Montan-Gesellschaft* dazu entschloss, auf ihrem Karl-Schachte in Köflach (Steiermark) eine Versuchsanlage

[1] HDI—Mitteilungen des Hauptvereines deutscher Ingenieure i.d. Tschechoslw. Republik 15. Jahrg. (1926), S.226 u.f.
Berg- u. Hüttenmännisches Jahrbuch d. Mont. Hochschule in Leoben Bd. 74, S.105 u.f.
Zeitschrift d. Oesterr. Ingenieur- u. Architektenvereines 1927, Hefte 13/14 und 15/16.
Sparwirtschaft 1927, Hefte 10 u.11.

für eine tägliche Leistung von etwa 20-25 t Trockenkohle zu bauen. Damit ist die genannte Firma als erste in Oesterreich dem Problem der wirtschaftlichen Braunkohlentrocknung nähergetreten. In der Abb. 1 ist eine schematische Darstellung dieser Versuchsanlage gegeben, an Hand welcher die Ausführung des Verfahrens erläutert werden möge. Zwei Kessel I und II sind in der gezeichneten Weise untereinander durch Leitungen verbunden und an eine Frischdampfleitung mit 8-10 Atü angeschlossen. Die Kessel besitzen oben durch Deckel verschliessbare Oeffnungen F_1 und F_2 zum Füllen und unten ebensolche E_1 und E_2 zum Entleeren. Je nach Stellung der Ventile A_1 und A_2 kann abwechselnd der eine oder der andere Kessel mit Dampf gespeist werden. Die Ventile B_1, B_2, C_1 und C_2 dienen dazu, je nach ihrer Stellung, das heisse Kondensat und den Dampf von einem Kessel in den anderen zu überführen, um die jeweils eingebrachte Frischkohle vorwärmen zu können. Ausserdem sind im unteren Teile des Kessels Abflussöffnungen D_1 und D_2 für die

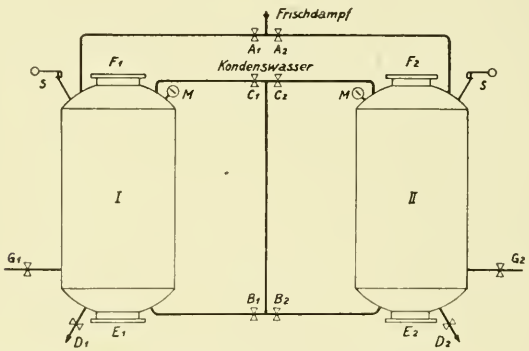

Abb. 1. Schema der Versuchsanlage.

Ableitung des Kondensates ins Freie vorgesehen, sowie auch Rohrstutzen G_1 und G_2 für die Luftzuführung zum Trocknen der Kohle im Kessel.

Der Betrieb ist ein abwechselnder. Nach Füllung des Kessels I mit Kohle wird Frischdampf zugeleitet, der anfänglich kondensiert. Dabei ist D_1 geöffnet. Sobald hier Dampf austritt, wird das Ventil geschlossen und solange Dampf zugeleitet, bis der Kessel auf den Betriebsdruck von 8-10 Atü gebracht ist und schliesslich der Druck etwa $1\frac{1}{2}$ bis 2 Stunden hindurch aufrecht erhalten. Hierauf wird durch Stellung der Ventile in den inzwischen mit Kohle gefüllten Kessel II entspannt. Nach erfolgter Entspannung wird durch den

oben geöffneten Kessel I Luft hindurchgeblasen, um die Kohle zu trocknen und schliesslich die getrocknete Kohle unten entfernt. Hierauf wiederholt sich dasselbe im Kessel II u.s.f.

Die Abtrocknung der Kohle nach erfolgter Dampfung und Entspannung kann auch ausserhalb der Kessel erfolgen, doch hat sich ihre Vornahme im Kessel selbst als praktisch erwiesen, da dadurch eine gewisse Stetigkeit in der Herstellung und im Betriebe erreicht wird. Auch beim Liegenlassen der gedämpften Kohle an der Luft findet unter Umständen schon eine weitgehende Abtrocknung statt.

Die Luft, die zum Abtrocknen in den Kessel eingeblasen wird, kann entweder in vorgewärmtem oder in kaltem Zustande verwendet werden. Meist genügt der in der Kohle aufgestapelte Wärmeinhalt, um kalte Luft verwenden zu können.

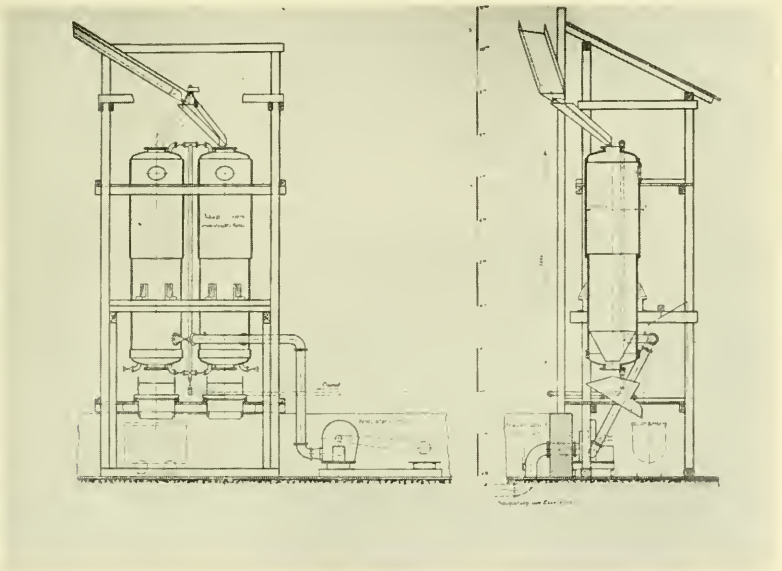

Abb. 2. Kohlentrocknungs-Versuchsanlage.

In der Abb. 2 ist die Versuchsanlage etwas eingehender dargestellt. Die Zeichnung, bei der alle unwesentlichen Details weggelassen wurden, bedarf auf Grund der früheren Erörterungen keiner näheren Erklärung.

Bei der Verwendung eines Dampfdruckes von etwa 8 Atü, wie er bei der eben beschriebenen Versuchsanlage verwendet werden

konnte, ergaben sich für die Trocknung der Köflacher Kohle folgende Zeitabschnitte: 20-30 Minuten Frischdampfzufuhr bis zur Erreichung des Betriebsdruckes von 8 Atü, 1½ Stunden Aufrechterhaltung des Betriebsdruckes, 20-30 Minuten Entspannung, 1-1½ Stunden Durchblasen von Luft. Dabei wurde ein Restwassergehalt von ungefähr 16% und damit eine Heizwertsteigerung auf durchschnittlich 4 800 Cal, gegenüber 3 600 Cal in der Rohkohle, erzielt.

Bei den Versuchen hat sich herausgestellt, dass der Abtrocknungsgrad wesentlich von der Höhe des Betriebsdruckes abhängig ist. Auch spielt dieser eine bedeutende Rolle hinsichtlich der Vermeidung des Zerspringens der Kohle. So hat sich bei der Köflacher Kohle als unterste Grenze ein Betriebsdruck von 4 Atü feststellen lassen; bei niedrigeren Drücken büsst die Kohle viel an ihrer Stückigkeit ein. Andererseits muss sich die Höhe des Betriebsdruckes nach dem ursprünglichen Wassergehalte der Kohle richten; je höher dieser ist, desto grösser muss auch der anzuwendende Druck sein.

Bei dieser Art der Kohlentrocknung lässt sich stets ein bedeutendes Schrumpfen der Kohle feststellen, dessen Mass wiederum von der Art der verwendeten Kohle abhängig ist. So beträgt die Schrumpfung bei Köflacher Kohle etwa ein Fünftel des ursprünglichen Volumens. Die Erscheinung hängt mit der Zerstörung der Kolloidstoffe zusammen und sie ist einerseits hinsichtlich des Dampfverbrauches und andererseits wegen der sonstigen Eigenschaften der getrockneten Kohle von Wichtigkeit. Bei dem Schrumpfen wird nämlich ein Teil des Kohlenwassers bereits ausgepresst und darauf ist es zurückzuführen, dass der Dampfverbrauch, der in der Versuchsanlage festgestellt werden konnte, ein sehr niedriger war, nämlich ungefähr 0,6-0,7 kg auf 1 kg zu entfernenden Wassers.

Die günstigen Ergebnisse der Versuchsanlage bestimmten dann die Oesterreichisch-Alpine Montan-Gesellschaft zum Bau einer Grossanlage, die anfänglich 280 t in 24 Stunden erzeugte und neuerdings auf die doppelte Erzeugung, also 560 t, vergrössert wurde. Die Anlage besitzt 8 Dämpfungskessel, die auf einen Betriebsdruck von 15 Atü gebaut sind, gegenwärtig jedoch nur mit 12 Atü betrieben werden, da die vorhandene Dampfanlage die Entnahme höher gespannten Dampfes nicht gestattet. Dabei wird die Kohle durchschnittlich auf ungefähr 14-15% Restwassergehalt getrocknet. Nach Aufstellung eines Zusatzkessels wird jedoch späterhin mit 15 Atü gearbeitet werden. Die Anlage ist in den Abbildungen 3 und 4 im Quer- und Längsschnitte dargestellt. Bei den Zeichnungen wurde der Uebersichtlichkeit wegen nur das Wesentliche berücksichtigt.

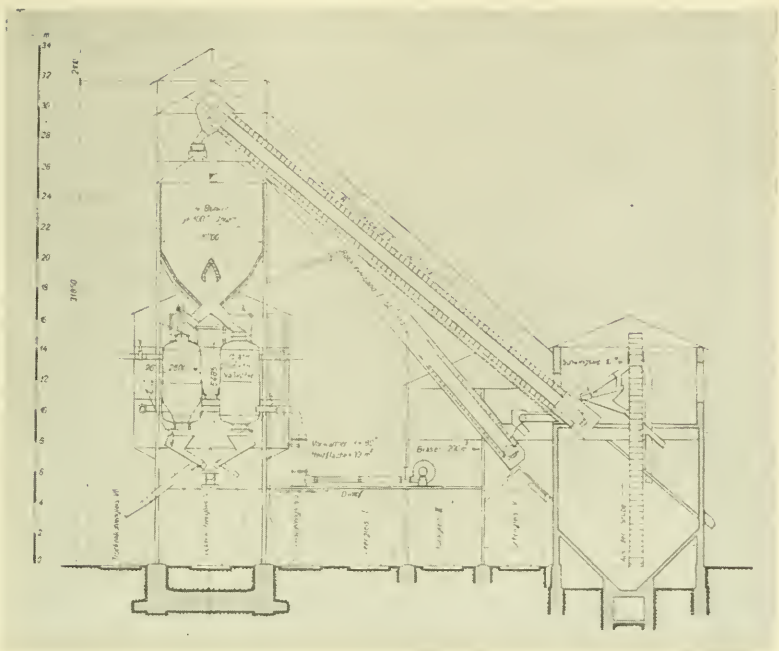

Abb. 3. Grossanlage (Querschnitt).

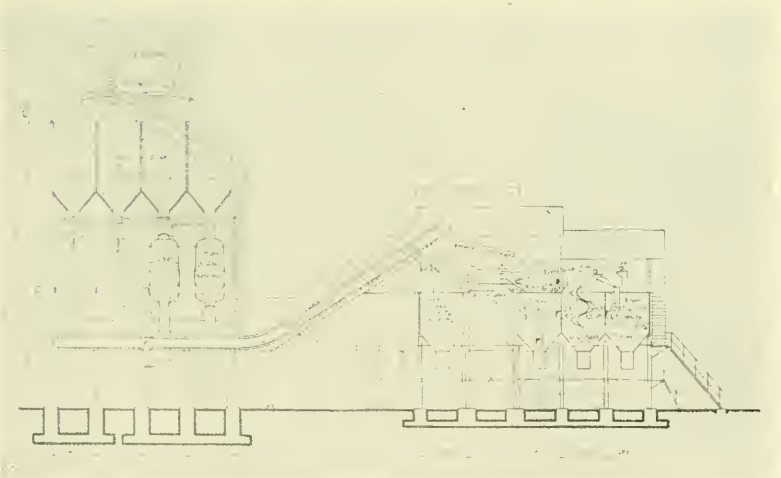

Abb. 4. Grossanlage (Längsschnitt).

Anfänglich war geplant, klassierte Kohle, sogenannte Mittelkohle (110-50 mm), zu trocknen. Es hat sich jedoch herausgestellt, dass es wirtschaftlicher ist, Förderkohle der Trocknung zu unterwerfen und erst die getrocknete Kohle zu klassieren. Deswegen ist, wie aus Abb. 4 hervorgeht, der Trocknungsanlage eine Klassierung angeschlossen.

Die hier abgebildete Anlage arbeitet, so wie die früher beschriebene Versuchsanlage, mit stehenden Kesseln, die abwechselnd betrieben werden. Es ist nicht zu leugnen, dass der abwechselnde Betrieb einen gewissen Nachteil bedeutet, jedoch kann der Betrieb so geführt werden, dass er gewissermassen kontinuierlich wird, indem die Kessel serienweise geschaltet und bedient werden. Aus dem Schema in Abbildung 5 geht hervor, wie sich die Verhältnisse bei 4 Kesseln, die mit 12 Atü arbeiten, gestalten. Bei der Verwendung von 8 Kesseln ist das Schema nicht mehr so übersichtlich, daher ist von dieser Darstellung Abstand genommen worden. Die im Schema angegebenen Zeiten sind etwas von den seinerzeit bei der Versuchsanlage festgestellten verschieden, was auf die Anwendung des höheren Druckes zurückzuführen ist. Im allgemeinen sind die Dämpfungszeiten umso niedriger, je höher der Druck ist. Mit der hier beschriebenen Anlage sind natürlich die Ausführungsmöglichkeiten nicht erschöpft, sowohl hinsichtlich Anordnung der Kessel, als auch des anzuwendenden Dampfdruckes.

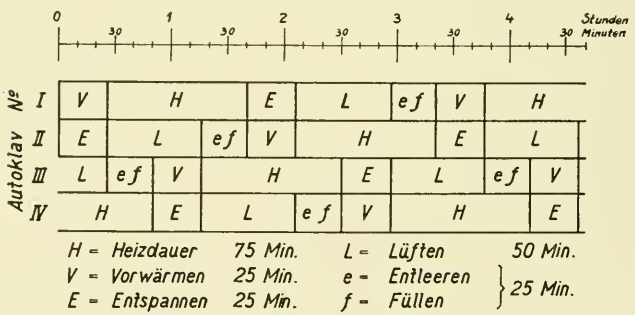

Abb. 5. Betriebsschema für eine Kohlentrocknungsanlage mit 4 Autoklaven.

Um ein Bild über die Wertsteigerung der Kohle beim Trocknen zu erhalten, möge die durchschnittliche Zusammensetzung der

Kohle im rohen und im betriebsmässig in der Grossanlage getrockneten Zustande angegeben werden.

	Köflacher Rohkohle (Mittel)	Köflacher Trockenkohle (Mittel)
Kohlenstoff	41,25%	55,02%
Wasserstoff	3,36%	4,43%
Sauerstoff u. Stickstoff ...	15,20%	20,03%
Wasser	35,20%	14,35%
Asche	4,88%	6,00%
Verbrennlicher Schwefel	0,11%	0,17%
Gesamt-Schwefel ...	0,25%	0,42%
Heizwert	3 634 Cal.	5 063 Cal.

Durch viele Versuche konnte nachgewiesen werden, dass der Aschengehalt in der Regel geringer ist als jener, der sich aus der Analyse der Nasskohle errechnet, wenn man den Wassergehalt der Trockenkohle zugrundelegt. Es ist darauf zurückzuführen, dass während der Dämpfungszeit ein Abwaschen und teilweises Auslaugen von Aschenbestandteilen stattfindet. Besonders bei manchen böhmischen Braunkohlen war der Unterschied sehr gross. Ausserdem findet bereits ein deutliches Fortsetzen der Inkohlung statt, was durch Feststellung und Untersuchung der beim Dämpfen entwickelten Gase nachgewiesen werden konnte. Bei der Dämpfung entwickelt sich aus 1 kg Köflacher Kohle eine Gasmenge von 875 cc, die zu 95% aus Kohlendioxyd besteht, neben sehr kleinen Mengen von Kohlenmonoxyd, Methan und Stickstoff.

Die getrocknete Kohle hat die Eigenschaft, nicht neuerdings Wasser aufzunehmen, was mit dem früher erwähnten Zusammenziehen der Kohle beim Dämpfen zusammenhängt. Dadurch, sowie durch die Beibehaltung ihrer Stückform, unterscheidet sie sich wesentlich von der durch Feuergase getrockneten Kohle, die sehr porös ist und daher auch viel leichter zum Selbstentzünden beim Lagern neigt. Durch viele Versuche ist dargetan, dass die nach erfolgter Dämpfung getrocknete Kohle vollständig lagerbeständig ist und auch beim längeren Lagern im Freien ihre Stückform nicht mehr verliert. Dadurch ist es ermöglicht, sie verschiedenen Verwendungszwecken zuzuführen, die für die Rohkohle nicht in Betracht kamen.

In erster Linie findet sie ausgedehnte Verwendung zur Herstellung von Generatorgas in Drehrostgeneratoren. Aus 1 kg Trockenkohle werden im Hüttenwerk zu Donawitz durchschnittlich 2,5 cbm Gas von folgender Zusammensetzung erzeugt:

Kohlendioxyd	3,5-4,0%
Kohlenmonoxyd	31,0-30,0%
Wasserstoff	14,0-15,0%
Methan	2,0%
Schwere Kohlenwasserstoffe	0,2%

Heizwert rund 1 500 Cal.

Des weiteren wurden Versuche vorgenommen, aus der getrockneten Kohle Wassergas herzustellen und zwar im Doppelgasgenerator nach *Strache*, welche Versuche günstige Ergebnisse zeitigten. Aus 100 kg Kohle wurde eine betriebsmässige Gasausbeute von durchschnittlich 67,2 cbm (reduziert auf 0° und 760 mm) oder umgerechnet auf kontinuierlichen Betrieb 73,7 cbm (0°, 760 mm) erzielt. Das erzeugte Doppelgas hatte durchschnittlich einen Heizwert von 3 040 Cal.

Die Verwendung der Trockenkohle zur Wassergasherstellung in den üblichen Generatoren ist deswegen möglich, weil sie eine weitere thermische Behandlung verträgt, ohne zu zerfallen. Die Kohle kommt im stückigen Zustande als Koks in den Vergasungsraum zum Unterschiede bei der Verwendung von nichtgetrockneter Kohle, die bereits vor der Entgasung beim Trocknen in viele kleine Stückchen zerspringt. Die Beibehaltung der Stückform beim Entgasen der Trockenkohle ist auch in allen jenen Fällen von Bedeutung, in denen man bei der Verschwelung auf einen nicht zu kleinstückigen Koks als Nebenprodukt hinarbeiten will. Die Köflacher Trockenkohle gibt beim Verschwelen einen Stückkoks von verhältnismässig grosser Festigkeit, besonders bei Anwendung höherer Temperaturen.

Zum Unterschiede von der Rohkohle eignet sich die Trockenkohle sehr gut für alle Arten von Heizeinrichtungen. Bei Kesselheizversuchen wurden je nach der Kessel- und Rostkonstruktion 4,5-5,5-fache Verdampfungen erzielt. Bei Kesselbelastungen bis zu 39 kg Dampf je Quadratmeter Heizfläche und Stunde sind Kesselwirkungsgrade bis 79% erreicht worden. Ferner haben Versuche dargetan, dass die getrocknete Kohle auch gut für Lokomotivheizzwecke Verwendung finden kann. Die bei den Probefahrten mit Köflacher Kohle erzeugte Dampfmenge erreichte das 5,2-fache des Kohlenverbrauches und dieser betrug im Durchschnitt 22,6 kg pro 1 000 t/km.

Aus dem Gesagten geht hervor, dass man mit Hilfe des beschriebenen Verfahrens imstande ist, aus den Ligniten, die sonst beim Trocknen zerspringen, einen hochwertigen stückigen Brennstoff zu erzeugen. Da es sich lediglich um eine Trocknung handelt, so erzielt man dabei in der Regel einen langflammigen Brennstoff, der für viele Arten von Feuerungen sehr gut verwendbar ist. Allerdings ist das Verfahren nicht für alle Lignite verwendbar, es ist vielmehr nötig, durch Kleinversuche vorher festzustellen, wie sich die Rohkohle beim Dämpfen und Trocknen verhält. Zahlreiche Versuche haben aber dargetan, dass das Verfahren für viele in- und

ausländische Kohlen brauchbar ist, wobei immer als Voraussetzung gilt, dass Wert auf die Erhaltung der Stückform beim Trocknen gelegt wird. Bei den Versuchen über das Verhalten der verschiedenen Kohlen ist besonders auf die Höhe des Druckes beim Dämpfen der Kohle Bedacht zu nehmen. Kohlen mit hohem Wassergehalt benötigen höhere Dampfdrücke als wasserärmere, um auf denselben Restwassergehalt zu kommen, ebenso wird auch das Erhaltenbleiben der Stückform durch Erhöhung des Dampfdruckes günstig beeinflusst. So gelang es bei einer deutschen Braunkohle mit über 50% Wassergehalt erst bei Anwendung eines Druckes von 20 Atü, auf einen Restwassergehalt von 18-20% zu gelangen. Bei Köflacher Kohle wurde bei Anwendung desselben Druckes eine Trocknung bis 9% erzielt.

Zum Schlusse möge ganz allgemein einiges über die Gestehungskosten der mit Dampf getrockneten Kohle gesagt werden. Diese setzen sich aus den Einsatzkosten und den eigentlichen Umwandlungskosten zusammen.

Die Einsatzkosten machen bei der Trocknung die Hauptpost aus. Bei der Köflacher Kohle ist zu berücksichtigen, dass man für 100 t Trockenkohle ungefähr 140 t Rohkohle benötigt. Die Wirtschaftlichkeit ist daher in erster Linie von den Gestehungskosten der Rohkohle abhängig.

Die eigentlichen Umwandlungskosten setzen sich aus den Kosten für den Wärmeaufwand, aus den Lohn-, Fracht- und Materialkosten, sowie jenen für die Amortisation und den Zinsendienst, zusammen.

Für das hier beschriebene Verfahren ist das Wesentlichste der Wärmeaufwand und deswegen möge nur darüber etwas ausgeführt werden. Es wurde bereits erwähnt, dass die Dampfmenge mit ungefähr 0,6-0,7 kg je 1 kg zu verdampfendes Wasser festgestellt werden konnte. Die überaus geringe Dampfmenge, die kleiner ist als die theoretisch notwendige, hat ihre Erklärung einerseits in dem Wesen des Vorganges beim Dämpfen der Kohle und andererseits in der Anordnung der Apparatur, die eine weitgehende Wärmeausnützung ermöglicht. Bei der Dämpfung der Kohle tritt bereits ungefähr ein Drittel des zu entfernenden Wassers in tropfbar flüssigem Zustande aus und läuft als Kondensat ab. Ein zweites Drittel des Wassers verdampft beim Entspannen des Kessels und da dieser Dampf zum Vorwärmen der frischen Kohle verwendet wird, wird die Verdampfungswärme von ungefähr 660-670 Cal je 1 kg Wasser zum grössten Teile nutzbar gemacht. So ist es erklärlich, dass zwei Drittel des aus der Kohle entfernten Wassers mit einem

Wärmeaufwand von nur 100 Cal je kg Wasser ausgetrieben werden können. Die meiste Wärme erfordert das letzte Drittel des zu entfernenden Wassers, das ist jenes, das durch die Durchlüftung entfernt wird. Im Gesamten benötigt man aber für 1 kg entfernten Wassers nur ungefähr 460 Cal.

Der Wärmeaufwand ist also geringer als bei den sonst üblichen Trocknungsverfahren. Zum Vergleiche möge darauf hingewiesen werden, dass z.B. die überaus günstig arbeitenden Röhrentrockner einen Wärmeaufwand von mindestens 900 WE je kg entfernten Wassers benötigen. Bei den in der Brikettindustrie üblichen Tellertrocknern und ähnlichen Einrichtungen findet man bekanntlich noch viel grössere Beträge hinsichtlich des Wärmeaufwandes.

THE DRYING OF BROWN COAL WITHOUT BREAKAGE

(ENGLISH VERSION—ABRIDGED)

In general, during the commercial drying of moist brown coal, breakage takes place, which, in most cases, considerably decreases the value of the coal. The large lignite fields in Austria will only be of interest from an economic point of view if the value of the coal can be increased by a reduction of the water content of from 35-45 per cent. to 13-15 per cent., which equals an increase in calorific value of from 3,600 to 5,000-5,100 cal. Until recently, all efforts in this direction met with failure, as the coal could not be dried without breaking up. A method of drying is now described by which the piece form is retained.

The coal is heated without allowing evaporation to begin until the coal lumps are of a uniform temperature throughout, so that the drying will then proceed from the centre outward. A temperature sufficiently high to cause the decomposition of the colloids is essential. The heating is best done in an autoclave by the direct application of steam under pressure. During the steaming of coal the lumps contract and evaporation is then started by the gradual reduction of the steam-pressure.

Encouraged by the success of the preliminary experiments, the Oesterreichisch-Alpine Montan-Gesellschaft decided to install a trial plant with a daily output of 20-25 metric tons dry coal at their Karl Pit in Köflach (Styria). The illustration of the plant (Fig. 1), shows two autoclaves, 1 and 2, connected with each other and to a steam plant of 8-10 atm. These autoclaves are each provided with two openings, one at the top (F_1, F_2) and one at the bottom (E_1, E_2). Either autoclave can be fed with steam by regulation of valves A_1 and A_2. Valves B_1, B_2, C_1 and C_2 serve to pass the steam and condensed products from one container to another in order to preheat a fresh charge of coal. Two valves, D_1 and D_2, permit the removal of condensed steam, and the air for drying is admitted through G_1 and G_2. Operation is alternate. Steam is passed in to the charged autoclave 1, in which it at first condenses and runs off through D_1; as soon as steam escapes at D_1, this valve is closed and

the pressure brought up to 8-10 atm., at which it is retained for about 1½ to 2 hours. The pressure is then released by opening the valves leading to autoclave 2, also charged with moist coal. Autoclave 1 is now opened at the top, and air passed through for drying, after which the autoclave is unloaded at the bottom. The same procedure is adopted with autoclave 2.

The actual drying after steaming need not take place in the containers, but the first method has proved to be better in practice.

The air blown through the autoclaves can be preheated or used at normal temperature. As a rule the heat stored in the coal permits of the use of cold air.

Details of the time required for drying Köflacher coal in the plant described, with a pressure of 8 atms., are as follows: introduction of steam for from 20 to 30 minutes to obtain pressure of 8 atms., which was retained for 1½ hours; 20 to 30 minutes for the reduction of pressure, and 1 to 1½ hours for treatment with air. The moisture was reduced to 16 per cent., the thermal value rising from 3,600 to 4,800 cal.

Low pressures cause the breaking of the lumps; the lowest pressure advisable for Köflacher coal was found to be 4 atms. The pressure is influenced by the amount of moisture in the coal, a coal of high water content requiring a proportionately high pressure.

The contraction of the lumps varies with the coal. Köflacher coal contracts about one fifth of the original volume. This is of importance, as during the contraction part of the water is pressed out of the coal, which fact can be regarded as the cause for the low consumption figure of about 0·6-0·7 Kg. of steam per Kg. of coal water in the trial plant.

The Oesterreichisch-Alpine Montan-Gesellschaft then installed a plant, at first capable of turning out 280 metric tons in 24 hours, which has now been increased and produces 560 metric tons. The plant consists of 8 autoclaves suitable for a pressure of 15 atms. The moisture in the coal is reduced to about 14-15 per cent.

It has been found more economical to screen the coal after drying than to dry sized coal. Fig. 4 shows the provision for screening attached to the drying plant.

Semi-continuous output is possible by a cyclic plan of operation with a 4 unit plant working at 12 atms.

The rise in value of the dried coal is shown by the analyses of moist and dried Köflacher coal. These show a decrease in moisture content from 35·20 per cent. to 14·35 per cent., with a consequent increase in calorific value from 3,634 cal. per Kg. to 5,063 cal. per Kg.

It has been found by the analysis of the gases produced during steaming that coalification progresses noticeably. 1 Kg. Köflacher coal gives 875 c.c. of gas which consist of 95 per cent. carbon dioxide, together with very small quantities of carbon monoxide, methane and nitrogen.

The contraction referred to above prevents the re-absorption of moisture after the coal is dried, an advantage in comparison with coal dried by the ordinary hot gas processes, which leave the coal very porous, in consequence of which it is also liable to the danger of spontaneous combustion.

Dried coal is largely used in the manufacture of producer-gas. At the Donawitz Steel Works a kilogram of dried coal gives approximately 2·5 cu. m. of gas of the following qualities:—

Carbon dioxide	3·5-4·0 per cent.
Carbon monoxide	31·0-30·0 per cent.
Hydrogen	14·0-15·0 per cent.
Hydrocarbons (heavy)	0·2 per cent.
Methane	2·0 per cent.
Calorific value	about 1,500 cal.

A successful attempt to produce water gas in a "Strache" double-gas generator yielded 67·2 cu. m. (0°C., 760 mm.), or in continuous operation 73·7 cu. m. (0°C., 760 mm.) per 100 Kg. coal. The calorific value of the gas averaged 3,040 cal.

Dried coal is used in the manufacture of water-gas, as it can be submitted to further thermal treatment without breaking.

In experiments using it as boiler fuel, the steam production amounted to 4·5-5·5 Kg. per Kg. With boiler ratings up to 39 Kg. per m^2 of heating surface per hour a boiler efficiency of 79 per cent. was obtained. Trials of Köflacher dried coal as locomotive-fuel gave a steam production of 5·2 Kg. per Kg. with a coal consumption of approximately 22·6 Kg. per 1,000 metric tons-kilometres.

In general it is shown that as a practical result of working this process the lignites are dried without breakage and the products are usually long-flame coals, but each case must be investigated on its merits as to the precise mode of application and the economic value of it.

In the case of Köflacher coal, 140 metric tons moist coal are required to produce 100 metric tons dried coal. Thus the cost of raw material is the principal item.

The chief item in the operating cost is not the heating. As referred to above, the amount of steam required, 0·6-0·7 Kg. per Kg. of the water to be removed, is very low. During steaming one third of the coal water to be extracted is mechanically expressed and runs off. Another one third is converted into steam on the release of the pressure, and as this is used for pre-heating in the next autoclave most of the heat content of 660-670 cal. per Kg. water is recovered. It will be seen that only an additional 100 cal. per Kg. of water is required to remove two thirds of the moisture. The final third requires the most heat for extraction, but a total of about 460 cal. per Kg. water extracted is necessary.

These figures compare favourably with those of other drying methods. For example, the tube dryers require at least 900 cal. per Kg. water, while it is a known fact that the figure for the plate dryers in the briquetting industry is higher still.

THE DEWATERING AND DRYING OF COAL

THE INSTITUTION OF MINING ENGINEERS

R. A. MOTT

Paper No. C3

CONTENTS

INTRODUCTION—DRAINAGE HOPPERS—DRAINAGE CONVEYORS—DEWATERING SCREENS—VACUUM FILTERS—CENTRIFUGES—DIRECT HEAT DRYERS—CONCLUSION—BIBLIOGRAPHY—RÉSUMÉ

Introduction

Coal as mined may contain water which is partly inherent and partly of adventitious origin. The inherent water (hygroscopic moisture) is that which a coal retains after air drying; the amount varies slightly with the hygroscopicity of the atmosphere but is generally characteristic for each coal. The adventitious water is that lost on air drying and is derived from pit water (in mines naturally wet) which is retained by fine coal on the surfaces of the particles and in the interstices.

The amount of inherent water in bituminous coals varies from less than 1 per cent. in many coals of high carbon content, to, say, 15 per cent. in some coals of low carbon content, but in brown coals and lignites may be as high as 40 per cent. In the coking coal districts of Great Britain the inherent moisture content of coals is generally low (less than 3 per cent.), but in other districts is higher, though rarely exceeding 10 per cent. The inherent water of coal is possibly present as an adsorbed layer on the colloidal particles in such thin films that a coal containing 15 per cent. would appear to be as "dry" to feel as one containing only 1 per cent. Large coal contains as much hygroscopic water as small coal from the same seam. Inherent water does not hinder grinding, for example, for pulverised fuel firing, and no attempt is usually made to remove it.

The amount of pit-water in coal as mined varies according to the proximity of water-bearing strata to the coal seams and according

to the amount of fines produced during mining. After mining, further adventitious water may be added (particularly to the fine coal), as rain during transport or storage in the open. The actual amount present in delivered coal as pit or rain water is usually small compared with the amount which may be added to the coal on subjecting it to a wet-washing process, and usually it is only for pulverised-fuel firing that water is removed from unwashed coal. In grinding for this purpose, adventitious or surface water binds together the small particles and prevents their dispersion in a cloud at the burner and it is usually considered to be desirable to dry the coal until no free or surface water remains. For other industrial processes surface water does not appear to be disadvantageous except in reducing the calorific value of the coal, and in incurring transport costs. Indeed, for boiler firing, for which most of the fine coal is used, it is often the custom to wet unwashed coal before use.

A large proportion of the fine coal produced in mining is cleaned by wet washing processes. Subsequently the wet coal is drained, dewatered or dried. The disadvantages of using coal containing excessive quantities of water have been described elsewhere,[1] and it is proposed to compare here the technical merits and the financial cost of the different methods available for water removal. Before doing so it is pertinent to consider the forces which retain water in the fine coal and the limits of water removal by the application of forces of different intensity.

Water removal in practice is usually confined to the surface water held by capillary forces in the interstitial spaces of the fine coal. The percentage of water so held depends on; (*a*) the size of the interstices, and (*b*) the proportion of the total apparent volume which they occupy. If the spaces are very large (as in nut coal), the weight of the water is more than sufficient to overcome the capillary forces and water readily drains away. Experimental trials have shown that it is not until the size of graded coal is less than about $\frac{1}{100}$ in. that the weight of the water in the interstices is balanced by the capillary forces and no interstitial water can be removed by natural drainage.

Results obtained for the natural drainage of different sizes of coal in a large funnel are given in Fig. 1. These results refer to one South Yorkshire coal, but have been confirmed for other coals. Each grade of coal was thoroughly wetted by water and drained

[1] The Cleaning of Coal, Chapman and Mott, 1928 (London, Chapman and Hall).

until continuous dripping ceased. The percentages of adventitious water are plotted against the average size of each grade of coal. The sizes used were $1\frac{1}{2}$-1, 1-$\frac{1}{2}$, $\frac{1}{2}$-$\frac{1}{4}$, $\frac{1}{4}$-$\frac{1}{8}$, $\frac{1}{8}$-$\frac{1}{16}$, $\frac{1}{16}$-$\frac{1}{20}$, $\frac{1}{20}$-$\frac{1}{40}$, $\frac{1}{40}$-$\frac{1}{80}$ and $\frac{1}{80}$-$\frac{1}{120}$ in. The results show that for coals between $1\frac{1}{2}$ and $\frac{1}{10}$ in. in size there is an approximately straight line curve relating size and percentage of water retained, the latter varying from 1·6 to about 10 per cent. At $\frac{1}{10}$ in. there is a point of inflexion and a second straight line curve relates the size and the percentage of water retained, but the inclination is very steep and the water content rapidly increases from 10 to 50 per cent. Earlier experiments[2] showed that for all closely-graded size of coals below $\frac{1}{100}$ in. the amount of water retained is constant at the maximum of about 50 per cent. It can be stated, therefore, that the amount of water retained by fine coal is dependent mainly on the percentage of material present less than $\frac{1}{10}$ in. in size.

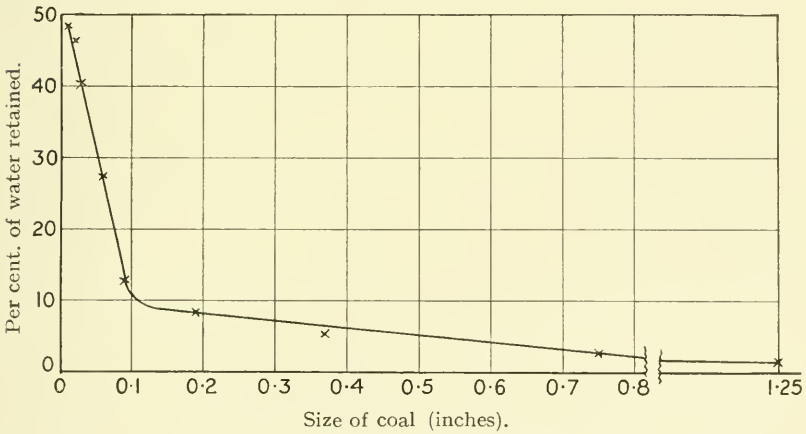

Fig. 1. Graph showing per cent. of water retained by different sizes of coal after natural drainage.

In graded nut sizes of coal in which there is little difference between the minimum and maximum sizes of the particles, the percentage of interstitial space (when the coal is loaded for example into a hopper) is the same for all grades and amounts to about 57 per cent. The maximum percentage of water which could be retained is therefore $\frac{57}{(57\times1\cdot0)+(43\times1\cdot3)}$ = 50 per cent. (taking the specific gravity of water as 1 and that of coal as 1·3). If the coal is agitated so that the particles take up the least apparent volume the

[2] *Loc. cit.*

percentage of free space is reduced to about 47 per cent. and the maximum amount of water which could be retained would be 40 per cent.

The amount of interstitial space can be further reduced if the variation between the maximum and minimum size of the particles is great (as in coal from 0 to $\frac{1}{2}$ in. size), for the smaller particles can fill the spaces between the larger ones. Mechanical agitation is usually necessary to produce efficient packing; with natural loading (as into a hopper) no reduction of interstitial space is obtained with a very small maximum size of particles (less than $\frac{1}{50}$ in.); with nut coal the interstitial space is partly reduced, but an increase in the capillary forces more than compensates for the decrease in the interstitial space, and less efficient dewatering is obtained by natural drainage. If, however, the mass of particles is agitated, the interstitial space is further reduced by efficient packing and the agitation partly overcomes the capillary forces. The maximum amount of water which may then be retained is about 30 per cent. This means that any dewatering device which induces complete pressure packing of the particles can reduce the water content of the finest coal slimes to 30 per cent.

If a stronger force is applied, for example, centrifugal force, the capillary forces can be still further overcome and further dewatering takes place. By intermittent contrifuging, graded sizes of coal as small as $\frac{1}{300}$-$\frac{1}{400}$ in. can be dewatered to less than 10 per cent., but only mixed or through sizes, with a maximum size of not less than $\frac{1}{10}$ in., can be dewatered to less than 10 per cent. water content by a similar centrifugal force. With smaller maximum sizes, centrifuging is less efficient and a force of greater intensity than centrifugal force, namely heat, is necessary to effect any considerable reduction in the amount of water retained.

These results of laboratory experiments are stated because it is important to show that there is a limit imposed by natural laws (as well as by mechanical difficulties) to the extent to which coal can be dewatered. A process inducing "pressure piling" of the coal particles can dewater coal to a lower limit than natural drainage in hoppers, and the application of suction or an impacting force, as in certain filters, dewatering screens and centrifuges, can effect still further dewatering. Complete removal of water can, however, only be obtained by the application of heat. The practical use of the various methods is usually governed, however, by their ability to handle large quantities of material for a given ground space, with little liability to breakdown, and at a low cost.

Drainage Hoppers

The simplest appliance used for water removal from coal is the drainage hopper. A drainage hopper is usually built of concrete, of square or rectangular section at the top and tapered at the bottom at an angle of about 60°. Each hopper may hold 100 tons[3] or more of coal. The coal after washing is raised from a sump by a drainage elevator with perforated buckets and loaded by a scraper conveyor, or circular table and plough, into the top of each drainage hopper in turn. The bottom of the hopper consists of a perforated plate or a rotating circular table. With the latter type an adjustable perforated cylinder may be raised to allow some coal to run out, the spaces between the coal particles being the equivalent of the perforations in the first type. The coal is allowed to stay in a drainage hopper for a period of 24, 36, or even 48 hours according to the fineness of the coal. With a common period of 24 hours, and a washing capacity of 400 tons of fine coal per day, four hoppers each of 100 tons capacity would be provided at a capital cost of about £3,000, including the scraper conveyor for loading. The limiting extent of dewatering can be judged from Fig. 1.

Hoppers are inexpensive in renewals and repairs, as there are no mechanically-moving parts. The only power required is that to elevate the coal and distribute it. For 400 tons per day (50 tons/hr.) elevated 50 ft. and distributed by a scraper conveyor, the power required would be approximately 12 H.P. or approximately 0·25 H.P. per ton. The labour requirements would be met by part of the time of one man.

Drainage Conveyors

The Baum drainage conveyor was formerly popular but it is now being replaced by simpler devices. It consisted of a series of perforated plates hinged to each other and carrying at the middle of each plate a double vertical partition also made of perforated plates. To each partition side plates were fixed to form a series of boxes into which the washed coal was loaded, the coarsest particles being put at the bottom with the slurry on the top. The conveyor was driven at a low speed of 8 in. per min. by rectangular drumheads. It was supported at intervals on rollers so spaced that the conveyor sagged between two adjacent rollers to compress the coal between the partitions, which were opened again when passing over a roller. This intermittent squeezing was designed to facilitate drainage, but

[3] Throughout this paper British units are used, the ton = 2,240 lb.

pools of wet slurry were frequently left on the top of the coal and drainage was, in practice, not always satisfactory.

The drainage conveyor induced, in part, pressure packing of the particles and could, therefore, dewater coal to a lower limit than drainage hoppers under the best conditions. The filtering of the dirty washing water with the slurry through the bed of coal led, however, to the deposition of clay slimes which hindered drainage, and in these circumstances the results were not altogether satisfactory. Actual results of dewatering by drainage conveyors will be given later in comparing this appliance with those which replaced it.

The capital cost of a drainage band to treat 400 tons of coal per day (50 tons/hr.), would be about £4,000. Owing to the heavy load imposed upon it (sometimes 2 tons per yard of length), renewals were frequently necessary, it being the practice in some plants to start replacing the links, etc., and gradually working through the whole conveyor as opportunities presented themselves; when the last set of links were replaced it was usually time to start on the first links again. The horse-power actually used was approximately the same as for a drainage (bucket) elevator, loading into drainage hoppers.

Dewatering Screens

The Simon-Carves Dewatering Screen.—The Simon-Carves dewatering screen consisted of a fixed, inclined screen (where removal of excess water took place) and two horizontal vibrating screens over which the coal passed in series. A second fixed, inclined screen was used for the slurry from the elevated settling tank, and the thickened slurry passed on to the vibrating screens on the top of the small coal.

One disadvantage of the arrangement was that the fixed inclined slurry screen often failed to remove the excess water from the slurry, and the vibrating screens were flooded, with a consequent loss of efficiency. To remedy this, separate sets of screens are now provided for the slurry and the fine coal, and the dewatering of the fine coal is not hindered by the slimes carried by the slurry water. For the slurry a finer mesh gauze is now suggested, with wedge wire for the fine coal screens. Each screen is suspended by ash hangers and is driven by a simple eccentric and a driving rod. By suitable adjustment of the eccentrics, the vibration due to the two screens can be balanced to a certain extent and smooth running ensured. In one instance the pulley made about 140 R.P.M. with a stroke of

about $1\frac{1}{2}$ in. The fine coal passes over a fixed inclined screen and then over two jigging screens in series. For slurry the arrangement may be similar except that the first inclined screen may also be vibrated by connecting it to the nearest suspended screen. The screen apertures are arranged longitudinally. When using separate slurry screens, instead of filtering the slurry on a bed of fine coal, a separate slurry effluent can be isolated and a much cleaner product results. For example at one washery the raw slurry fed to the screens contained 26·6 per cent. of ash and contained 36·8 per cent. of material less than $\frac{1}{100}$ in. with about 50 per cent. of ash. The dewatered slurry contained 9·7 per cent. of ash and included only 11·7 per cent. of material less than $\frac{1}{100}$ in. and the average ash of this fraction was reduced to 33·7 per cent. Much of the clay slimes, therefore, passes through the slurry screen, but some fine coal particles are also rejected; it is possible by settling to recover some of the coal particles if desired, but the improvement in the quality of the coal and the more efficient dewatering would probably more than compensate for any loss of coal.

The capacity of the dewatering screen varies according to the grading of the coal treated, but up to about 4 sq. ft. are required per ton of coal, and up to 18 sq. ft. per ton of slurry. A set of four screens, each 6 ft. 6 in. by 3 ft. 7 in., to treat 400 tons of fine coal and slurry per day (50 tons/hr.), would cost about £2,000. A brass wedge-wire screen lasts about nine months. The renewals cost is, therefore, the biggest factor in upkeep. For example, in one South Yorkshire washery the upkeep costs per ton of slack are as follows:—

	Pence
Attendance	0·42
Repairs	0·05
Renewals	0·39
Total	0·86

The power requirements are about 0·3 H.P. per ton. In practice, well-designed screens require little attention except oiling. On the other hand, a badly-designed screen may prove prohibitive in renewals cost. The writer knows a dewatering screen which was recently introduced but proved a complete failure. The appliance consisted of an inclined and a horizontal screen fixed together and driven as one unit. Each screen was 10 ft. long by 2 ft. 6 in. wide but the arrangement was so clumsy, and the screens so badly balanced that no screen was in operation for a period longer than five weeks. The power consumption was 0·5 H.P. per ton of (dry) coal. The

re-inforcing bars of the screen broke and the wedge wire gaped; usually two double screens were standing idle for repairs, and the overloading of the remaining screens made the dewatering most unsatisfactory, the repair costs prohibitive, and seriously hindered the smooth working of the washery. The vibration produced in the washery building was sufficient to arouse fears for the stability of the building. Dewatering screens require careful designing, good balancing, and smooth running to be successful.

Dewatering screens are more effective than the old drainage band, and comparative figures can be given for the amounts of water in the fine coal after treating as in Table I.

TABLE I.

COMPARISON OF AVERAGE WATER CONTENT OF COAL AFTER TREATMENT ON DRAINAGE BAND AND DEWATERING SCREENS

Size of Slack. In.	Drainage Band.	Dewatering Screens.
$\frac{5}{16}$	23-25	19-20
$\frac{3}{8}$	23	18
$\frac{3}{8}$	22	16·8
$\frac{3}{4}$	14	11·1
$\frac{7}{8}$	—	10·0

These figures refer to the combined product of fine coal and slurry. The slurry from the settling tank of a Baum washery can usually be dewatered to about 30 per cent. on a dewatering screen, and with this water content it can be distributed fairly evenly with the fine coal. There is a tendency for it to form balls on the dewatering screen, but these are readily crumbled.

The Rheolaveur Dewatering Screen.—The Rheolaveur dewatering screen, which has been largely used on the Continent, consists of a rectangular wedge wire screen supported on inclined flexible legs. The motion imparted by an eccentric running at about 250 R.P.M. gives alternately a forward and rising motion and a backward and downward motion which causes the coal to pass forward in a series of hops. The brass wedge wire used has 0.5 mm. ($\frac{1}{50}$ in.) spaces. The screening area per ton of coal is given as 2·4 sq. ft. per ton of coal of 0 to $\frac{3}{8}$ in. size. For a capacity of 50 tons/hr. the capital cost is about £450 (excluding motor), the power requirements about 0·2 H.P. per ton, and the cost of renewals and repairs about 0·6d. per ton.

For slurry, copper gauze of 0·25 mm. ($\frac{1}{100}$ in.) mesh is used mounted on $\frac{3}{4}$ in. square mesh perforated plates. About 7·4 sq. ft. are required per ton of slurry. The capital cost is about £175 (excluding motor), the power requirements about 0·5 H.P. per ton, and the cost of renewals and repairs about 1d. per ton of slurry. In one

test, a slurry containing 38 per cent. of $\frac{1}{16}$ to $\frac{1}{100}$ in. particles, and 57 per cent. less than $\frac{1}{100}$ in., the water in the dewatered product was 35·9 per cent. The dewatering screens on which the product from the Rheolaveur slurry washers are treated are fitted with water sprays to remove the finest slimes.

The H.H. Dewatering Screen.—The earlier H.H. dewatering screen consisted of a phosphor bronze wedge-wire screen of 0·25 mm. apertures, supported on an ash or hickory legs and driven by an unbalanced loose pulley. The forward stroke imparted to the table screen was terminated by a bumping block, which tended to jerk the material along the screen. The unbalanced pulley rotated at 240 R.P.M. The coal on the screen impinged against a number of "box weirs" (or dams with lids) to facilitate dewatering. A screen $6 \times 1\frac{1}{2}$ ft. could treat 7 tons of coal per hour.

The table was built of heavy gauge to withstand the shock due to bumping, but it was found that in practice nuts tended to work loose, reinforcing bars to break, and the wedge wire to gape. For this reason the bumping block has now been discarded and a table is built of lighter sections. The dewatering is not so effective but the smoother working is found to be advantageous. The box weirs are no longer used. The new design of screen with 14 sq. ft. of screening surface treats approximately 6 tons of fine coal per hour using about 1 H.P., and costs £90.

A simple device for dewatering coal has been introduced at Denaby and Cadeby Collieries, Yorkshire, by the washery manager. It consists simply of inclined and horizontal wedge wire screens, which are fixed, and a scraper which pushes the coal forward on each screen. The wooden scraper has a contact strip of brass and is connected by a rod to a crank. Since the heavy screens and the coal treated are not lifted, the power required to operate the rakes is negligible, and because the screens are fixed the renewals and repairs costs are very low. In practice, $\frac{7}{16}$ in. slack is dewatered to 15 per cent. at one washery, and, at the other, $\frac{3}{8}$ in. slack, after a further treatment of 50 min. on a drainage conveyor, is dewatered to 12 per cent. This simple device is worthy of attention particularly for fine coal (excluding the slurry).

Vacuum Filters

Rotary Filters.—A number of different types of rotary vacuum filters have been applied to the dewatering of very fine coal, slurry or slimes, particularly after cleaning by froth flotation. In general, a drum about 8 ft. long and 8 ft. diameter is fitted with a filter gauze

or cloth, and rotates in a tank containing, say, the flotation concentrate. The internal surface of the drum is connected by a large number of pipes to a vacuum pump, and, by the suction, a cake is formed on the filter surface. The filter cake is subjected to a high vacuum during most of one revolution, when it is removed from the drum by a scraper or by the application of compressed air. Some results obtained with a rotary vacuum filter are given in Table II.

TABLE II.

RESULTS OF DEWATERING WITH ROTARY VACUUM FILTERS

Place.	Type of Filter.	Final water content %.	Filter surface per ton of (dry) coal per hr. sq. ft.	Power per ton of (dry) coal. H.P.
Oughterside, Cumberland	Oliver	17	15	3·3
Germany	—	20	—	—
Limburg, Holland	Wolf	20	9·5	—
Mont Cenis, Germany	—	20	16	—
Ilseder-Hütte, Germany	Wolf	18	7	2·2

It will be observed that the capacity of these filters compares favourably with that of slurry dewatering screens, and the extent of dewatering is greater, but the power consumption is higher. One of the largest filters made has 200 sq. ft. of filter surface. It is about 8 ft. in diameter and about 9 ft. long and occupies about 20 × 11 sq. ft. of ground space. In addition, space has to be found for a vacuum pump, vacuum receiver, a barometric discharge pipe, a filtrate pump and, possibly, an air blower to free the cake from the screens. The actual space required is, however, not great and the accessories can be arranged in a number of different ways. Such a filter would handle from 13 to 26 tons of (dry) coal per hour. A Wolf filter of 6 sq. m. filter surface (64 sq. ft.), would cost about £800.

Rotary vacuum filters cannot be compared directly with the other dewatering appliances described, as they can only be used for very fine coal (slurry). As this material holds the most water, its dewatering is of the greatest importance.

A new type of rotary vacuum filter has been introduced by the Dorr Company, called the Dorrco filter. It differs from other rotary filters in that the filter cake is made on the inside surface of the drum, and the vacuum pipes are more conveniently disposed externally. The material is fed to the lower half of the drum and

forms a natural bed with the heavier and larger particles on the screen surface; this facilitates dewatering. Suction is applied to the cake until it reaches the highest part of the drum, when the vibration of the screen surface causes it to drop into an internal hopper, whence it is discharged by a screw conveyor. About 20 sq. ft. of screen surface are said to be required per ton of coal per hour to dewater to about 20 per cent. of water. A filter 12 ft. in diameter and 14 ft. long, occupying about 200 sq. ft. of floor space, and treating 20 tons of coal per hour (flotation concentrates), would cost about £2,250 with all accessories. The power requirements would be about 43½ H.P. or 2·2 H.P. per ton.

Plan Filters.—Vacuum filters are also made with a filtering surface in one horizontal plane—the Plan filter. Such a filter is circular, with the suction pipes arranged underneath (Wolf), or radially by cutting out the central portion of the table (Gröppel). The screen surface is wedge wire laid in sections each of which is connected by a pipe to the vacuum pump. A Wolf Plan filter of 6 sq. m. filter surface (64 sq. ft.) would cost about £900 with a further £250 for the vacuum pump, receiver and filtrate pump. The power consumption would be 26-29 H.P.

Centrifuges

A number of centrifuges have been used in this country to dewater washed coal, the most noteworthy being the Hoyle, the Elmore and the Carpenter.

The Hoyle Centrifuge.—The Hoyle centrifuge consists of a vertical cylindrical screen basket and a scraper spiral rotated by differential gearing. The screen basket, made of steel wedge wire, rotates within a casing at about 600 R.P.M., and the scraping spiral rotates within the screen basket at a slightly lower speed. The screen basket is fastened by a spider casting to a solid steel shaft, and the scraping spiral is connected to a hollow or quill shaft revolving round the inner one. The screen basket and scraping spiral are driven through suitable gearing from a countershaft.

The coal is fed to the centrifuge from a hopper and is flung by centrifugal force on to the basket screen, from which it is scraped by the spiral, and drops into a hopper below. At one South Yorkshire colliery, about 30 tons of coal may be treated per hour and dewatered from about 18 to 10 per cent. The coal is less than ⅝ in. in size but some of the dust is removed by vibrating screens before washing. Some fine particles pass through the screen with the water removed and are collected in a pond. The capital cost is about

£1,200. The running costs at this colliery are stated to be (per ton of dry coal):—

	Pence.
Repairs	1·31
Labour	1·00
Total	2·31

The power consumption is about 1 H.P. per ton of (dry) coal.

The Elmore Centrifuge.—The Elmore centrifuge consists of a rotating screen basket with a scraper rotating inside it at a somewhat lower speed. The drive differs from that used in the Hoyle, in that the motion of a horizontal belt-driven countershaft is transmitted to a vertical countershaft from which different sizes of gear wheels actuate a solid shaft to drive the scraping flights, and a quill shaft to drive the screen basket. The screen is inclined outwards from top to bottom, and the ten scraping strips almost touch the screen and are inclined also to the direction of rotation. Coal is fed to the centrifuge from a hopper and is flung on to the screen surface where the scraping flights remove it. The dewatered coal drops through an annular space between the outer casing and the central gear box; the water removed passes through the screen into a launder.

In the Elmore centrifuge, the ten scraping plates are nearly vertical whereas the spiral scraper in the Hoyle centrifuge gives in effect two horizontal and two vertical scraping plates. In the Elmore centrifuge, therefore, the coal is not left on the screen for any length of time and at any one instant the thickness of coal must be less than in the Hoyle centrifuge. Moreover, the inclination of the Elmore screen to the vertical enables use to be made of the reaction of the force of impact on the screen. This reaction tends to deflect the coal downwards, throwing less duty on the scraping flights. For these two reasons the power consumption is lower with the Elmore centrifuge, and a higher output is attained. The standard 4 ft. machine has a capacity of 80 tons per hour.

The capital cost of such a machine is about £1,900. The repair costs at a South Yorkshire colliery are 0·178d. per ton of coal treated. At this colliery the washed coal was dewatered from about 20 to 7·4 per cent. (average of 18 daily tests). The raw coal was less than $\frac{1}{2}$ in. but contained only about 24·2 per cent. less than $\frac{1}{8}$ in. The screens used are thin phosphor bronze sheet with inclined slots $\frac{1}{2}$ by $\frac{1}{16}$ in., or punched steel plate with $\frac{1}{16}$ in. round holes. These thin plates are fitted inside the steel basket, which has $\frac{1}{4}$-in. peripheral slots. A difficulty is experienced in laying the renewal screens truly against

the basket. Any irregularity tends to be torn by the scraping flights, and coal may build up against a torn edge and throw a back pressure on the driving mechanism. The screens, however, are cheap and may be quickly replaced.

In practice, the fine coal which passes through the screens with the water may be returned to the slurry-settling tank of the washer and returned for treatment.

The Carpenter Centrifuge.—The Carpenter centrifuge, unlike those previously described, does not use a scraping system and, therefore, needs only a simple drive. It consists of a stepped truncated cone fastened to a vertical shaft by spider castings at the top and bottom, and rotated within a casing. Each step of the cone comprises one screen and between each screen a set of serrated teeth breaks up the coal mass as it leaves one screen to be flung on to the next. The screens are inclined to the vertical at an angle of about 45° (compared with 20° for the Elmore), and the reaction from impact on the screen is sufficient to deflect the coal downwards without using a scraper. On the other hand, the absence of a scraping system results in a thicker bed of coal being left on the screens and the power consumption is higher than in the Elmore machine.

At Nunnery Colliery, Yorkshire, a Carpenter centrifuge was first driven at a speed of 360 R.P.M. and dewatered washed coal through $\frac{7}{8}$ in. (with 22 per cent. through $\frac{1}{8}$ in.) to about 5 per cent. By reducing the speed of the centrifuge to 270 R.P.M., the extent of dewatering was from 18 or 20 per cent. to 6 or 7 per cent. The screen plates were made of $\frac{1}{8}$ in. steel plates with $\frac{1}{8}$ in. holes, $\frac{3}{16}$ in. between centres. Under these conditions, about 5 per cent. of the (dry) feed coal passed through the screens with the water. This is passed over a $\frac{1}{16}$ in. screen plate in the floor of a trough to remove the finest particles and the bulk of the water. The oversize passes into wagons indirectly, and, since the finest slimes are absent, the water content is reduced to 15 per cent. by natural drainage. This coal is then added to the dewatered coal from the centrifuge, giving a coal to the ovens containing about 8 per cent. of water. The undersize from the screen passes to a tank from which it is ejected to a series of troughs which surround the top of the centrifuge building. By placing dams in the troughs, the solids settle and an effluent containing about 1 per cent. of solids passes to final settling ponds to recover coal for boiler firing. The settled solids are returned to the centrifuge hopper. In this way no accumulation of slurry takes place.

The centrifuge has now been in operation at Nunnery for a period

of over 3 years. It is run during two periods of about 5 hours in each for two shifts and has treated the 300 tons of coal required daily for the coke ovens at a rate of 30-40 tons per hour. The power consumption is slightly less than 1 H.P. per ton of coal treated. The repair costs for the first seven months were stated to be 0·12d. per ton of coal; subsequently they are said to be less than $\frac{1}{4}$d. per ton. The capital cost of a Carpenter centrifuge of 50 tons per hour nominal capacity is £2,300, including steel framework and driving pulley, but excluding hoppers, feeding arrangements, motor, etc.

At Messrs. John Lysaght's, Scunthorpe, two Carpenter centrifuges have been in operation since the end of the 1926 coal stoppage. Each is of 50 tons per hour nominal capacity and is operated for about $7\frac{1}{2}$ hours per day at slightly below its nominal capacity. The coal treated comes from about fourteen different sources. The average grading shows about 100 per cent. less than $\frac{1}{2}$ in., 40 per cent. less than $\frac{1}{8}$ in. and 26 per cent. less than $\frac{1}{16}$ in. Some of the finest dust is removed by a Coppée suction apparatus and is added, unwashed, to the remainder of the dewatered coal. Originally the centrifuges were run at 460 R.P.M. but have been slowed down to 400 R.P.M. at which speed the coal is dewatered from 15 or 20 per cent. to 9 or 10 per cent. The power consumption is about 1 H.P. per ton, and during a test period of four months the repairs cost was 0·433d. per ton (made up of 0·23d. for renewals and 0·20d. for labour). About 10 to 12 per cent. of the (dry) coal passes through the screens of the centrifuge with the effluent water and is run to rectangular concrete settling ponds at ground level. The overflow from these ponds passes to a circular slurry pond where the finest particles settle. The coarser particles of slurry from the first set of ponds is loaded into wagons and in shunting is dewatered to about 15 per cent. water content. The final slurry pond is only occasionally emptied and the slurry is used for boiler firing.

The problem of slurry handling is intimately associated with the use of centrifuges for coal dewatering. From 5 to 12 per cent. of the dry coal may pass through the centrifuge screen as slurry, and the whole success of the installation may depend on how this is handled.

Direct-Heat Dryers

The commonest form of direct-heat dryer is a horizontal rotating cylinder in which lifting plates are fixed to cascade the coal in a stream of hot flue gas. In Germany, several forms of dryer, the Büttner, the Rhineland, the Imperial, the Dürr, the Grevenbroich,

etc., use various types of "honey-combing" as a filling to allow the coal to drop from cell to cell, with frequent overturnings, before it reaches the floor and is again raised. In Great Britain probably the most popular dryer of this type is the Ruggles-Coles (Edgar Allen) dryer. This consists of two inclined concentric cylinders, the outer one being supported on suitable roller bearings and driven at about 12 R.P.M. by a pinion and gear ring riveted to the outer casing. The two cylinders are rigidly connected at their mid-lengths by spider bracing and additional support (whilst allowing for differential expansion) is given by swinging braces at other points. Twelve lifting flights are equally spaced in the cross section of the outer shell and are extended along the whole internal length; six lifting flights are also fitted to the inner cylinder. The inner cylinder is extended to receive hot flue gases from a furnace, the hot gases passing through the inner cylinder and returning outside it to a fan mounted on the top of the furnace. Coal is fed to the furnace end of the annular space and is lifted by the flights to drop on to the hot inner casing. The coal is heated indirectly (when the furnace gases are hottest) and directly (when they have been cooled by passing along the inner chamber) before being discharged at the lower end. The waste gases and water vapour are discharged by the fan into a cyclone to collect the dust.

The temperature of the gases entering the inner cylinder is about 730°C. and falls to about 180°C. before it enters the annular space, and to about 65°C. at the exhaust fan. A dryer with a length of 55 ft. and an external diameter of 7 ft. 6 in. has a capacity of about 20 tons of coal per hour in drying from 5 per cent. to less than 1 per cent. The overall ground space is about 75 × 12½ ft. The power requirements are about 20 H.P. for the rotation of the barrel and about 5 H.P. for the fan. Such an appliance, including feed table, driving motor and gear, brickwork foundation and erection, with the plant ready for operation, costs about £1,800. In addition, about 4 lb. of coal are required per 1 per cent. of water removed from each ton of coal. The fuel costs cannot be considered as an extra charge, for at least half the amount of fuel would be consumed in evaporating the moisture in the furnace if undried coal were fed. The upkeep costs of a simple rotary dryer are low since the movement is smooth, and the moving parts are simple in type.

The H.H. Dryer.—Another type of direct-heat dryer—the H.H.—is disposed vertically and is stationary. The cylinder is divided into four compartments, each of which consists of a horizontal tray with an inverted metal cone above it. The coal is scraped by

rotating rabbles from one tray to its outer edge and falls into the cone of the compartment below, and so on. The cones are perforated and a current of hot flue gas, passing up the dryer, comes into intimate contact with the coal. A subsidiary hot gas inlet feeds the upper two compartments. The waste gases are discharged through a cyclone, and the dried coal by a worm conveyor.

Dryers to deal with 10 to 40 tons of coal per hour have an approximate overall height of 33 ft., and ground space of 33 ft. by 18 ft. A 10-ton dryer has a diameter of approximately 11 ft., and a 40-ton dryer, 15 ft. A dryer to deal with 40 tons per hour and reduce the moisture from 15 to 6 per cent. would cost about £2,800. The power requirements are approximately 1 H.P. per ton and the fuel necessary would be about $\frac{1}{2}$ ton per hour.

A vertical dryer has more moving parts than the simple horizontal dryer, and breakdowns, irregular flow of coal, and overheating are more liable to occur. The ground space is, however, considerably less and the dry coal-handling equipment simpler. With both types of dryer, nuisance may arise from the fine dust carried along by the hot gases which is not settled in the cyclone. In some recent installations, bag filters and Lodge Cottrell dust catchers have been used to prevent this from being discharged into the atmosphere.

The Lopulco Dryer.—This consists of a stationary vertical cylinder with an internal rotating frame carrying sixteen circular tables arranged in tiers. Each table is made of cast iron and has a set of steam coils cast inside it with inlet and outlet connections to the central revolving frame. The central frame and the tables are rotated by a pinion engaging on an internal rack on a spider casting at the top of the dryer. Coal is fed to the dryer by means of a plough and a revolving table and is spread uniformly over the first table by a spreader bar. Towards the end of one revolution the coal is scraped into a shoot which discharges it on to the table below, where the treatment is repeated, and so on. Air is admitted through perforations in one vertical section of the outer casing of the dryer and passes over the coal in each table, being withdrawn at a point opposite its inlet to a main common to all the tables. The velocity of the gases is therefore low. A quantity of $7\frac{1}{2}$ tons per hour is treated by an appliance occupying a ground space of 13 × 10 ft., using 50 lb. of steam per 1 per cent. of water removed.

Conclusion

No one type of dewatering or drying appliance can be recommended for all requirements, and some are of very special application.

For example, the power consumption of direct-heat dryers and suction filters is as high if not higher than the total power requirements of a normal washery. On the other hand, slurry cannot be dewatered below 30 per cent. without recourse to these methods of treating, and in certain circumstances the power consumptions may be justified. The power used by efficient centrifugal dryers, although higher than that for dewatering screens, is efficiently used in effecting a greater dewatering. The power requirements and capital cost per hour of different appliances are given in Table III.:—

TABLE III.

POWER REQUIREMENTS AND CAPITAL COST OF DEWATERING AND DRYING APPLIANCES

Appliance.	Horse power per ton		Capital cost (per ton/hr.	
	Fine coal.	Slurry.	Fine coal.	Slurry.
Drainage hoppers ...	0·25	0·25	£50–60	£50–60
Drainage conveyor ...	0·3	0·3	£80	£80
Dewatering screen ...	0·2–0·4	0·5	£10–40	£10–40
Suction filters ...	—	2–3	—	£120
Centrifuges	0·5–1	—	£25–50	—
Direct-heat dryers ...	1·25–4	2–4	£70–90	£70–90

The cost of maintenance of efficient centrifuges is quite low, and compares favourably with the cost of dewatering screens.

Poor coking coals may deteriorate by oxidation in a period of even a few days, and, for such coals, all forms of mechanical dewatering appliances have an advantage over drainage hoppers in eliminating the time for natural drainage. Dewatering screens are rapidly establishing themselves for dewatering washed slack for coking purposes, but efficient centrifuges are worthy of greater attention than they have recently received. Unfortunately, they cannot be used for slurry alone. Hoppers for drainage and drainage conveyors may both be considered to be obsolescent; the argument that drainage hoppers also provide storage accommodation may be met by referring to the high capital cost of a large number of small drainage hoppers, and the power required in elevating and distributing; it is preferable to allow extra storage bunker space by one large bunker after dewatering the coal by dewatering screens or by centrifuging. Suction filters are too expensive and use too much power to recommend for general purposes but may find application in special circumstances. Direct-heat dryers are primarily of importance for drying coal for powdered-fuel firing, for which purpose they alone are satisfactory. For other purposes they are expensive, use a lot of power, and except in the simplest design there may be a danger of local overheating. In washeries where the slurry is recovered separately, the use of a centrifuge for the

fine coal alone and a direct-heat dryer for the slurry is worthy of consideration. With this combination the centrifuge would dewater the fine coal to say 5 per cent. water content without passing much coal through the screens, and the slurry could be dried to say 10 per cent. water content.

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RÉSUMÉ

Après avoir défini la nature de l'eau intégrante et accidentelle du charbon, l'auteur reprend la question des forces par lesquelles l'eau est retenue dans le charbon. A l'aide de données expérimentales et d'un graphique, il démontre ensuite la relation entre la grosseur du charbon et la quantité d'eau accidentelle retenue après l'asséchement par écoulement sous pesanteur. S'appuyant sur les bases théoriques l'auteur étudie la question de la limite d'asséchement par écoulement sous pesanteur, par écoulement forcé et par égouttage.

Ensuite sont décrits en détail les différents appareils qui sont employés pour égoutter le charbon, à savoir: tours d'égouttage, tamis égoutteurs, convoyeurs égoutteurs, cribles, filtres à vide, essoreuses et séchoirs thermiques. En même temps que la description de tous ces appareils, l'auteur cite les frais de premier établissement pour une capacité donnée, la consommation de force motrice et, quand c'est possible, les données actuelles sur les frais d'entretien.

Après avoir considéré les difficultés appartenant à l'usage de chaque appareil, l'auteur, en conclusion, est d'avis que les tours d'égouttage et les convoyeurs égoutteurs tombent en désuétude; que les cribles s'établissent rapidement en faveur comme des appareils possédant une grande stabilité de marche et servant à l'égouttage continu et économique des fines lavées du charbon à coke; que l'égouttage du charbon par les essoreuses peut être plus complet que par les cribles, et quoique la consommation d'énergie méchanique des premières soit plus élevée, les frais d'entretien ne sont pas élevés; que l'inconvénient des essoreuses consiste en ce que l'on ne peut pas les employer pour l'égouttage des schlamms. De plus, l'auteur fait remarquer que l'on ne peut pas employer les filtres à vide pour d'autres buts spéciaux à cause de leurs frais élevés d'installation et d'exploitation. Tandis que l'on emploie les séchoirs thermiques premièrement pour le séchage de charbon pulvérisé, leur emploi pour le séchage des schlamms mérite d'être considéré.

THE CLEANING OF SMALL COAL

THE INSTITUTION OF MINING ENGINEERS

DR. W. R. CHAPMAN

Paper No. C4

CONTENTS

THE SIZE OF SMALL COAL—COAL-CLEANING PROCESSES—THE CHOICE OF A CLEANING PROCESS—THE COST OF COAL CLEANING

RÉSUMÉ

The Size of Small Coal

For the purposes of this paper small coal may be considered to be that portion of a pit's output that can be cleaned more cheaply by a mechanical process than by hand picking. The actual size, therefore, at which coal ceases to be large coal and begins to be small coal differs in different countries, in different coalfields in any country, and at different pits in any coalfield. Small coal itself is divisible into nuts and fines, but the dividing line is again ill-defined.

It may be accepted generally that coal too large to pass through the apertures of a 4-in. round-hole screen must always be cleaned by hand picking, although larger coal than this can be cleaned in certain washers. At some collieries, however, it is considered satisfactory to hand pick the nut sizes of the coal from about 4 to 2½ in., and at many collieries the coal is hand picked down to 2½ in. and the smaller coal is not cleaned at all.

Taking efficiency into account, the actual size at which it becomes more economical to clean the coal mechanically than to hand pick it, is probably larger than is usually thought to be the case. It depends upon the nature of the raw coal, the degree of cleaning required, and especially upon the amount of shale in the coal and the proportion of middlings. Isolated particles of shale 3 in. in size can easily be distinguished and removed from the coal,

but if there is any quantity of intergrown and laminated middlings particles, or of coal particles enclosing pyrites, the coal below 3 in. in size cannot be hand picked efficiently. In British coals, middlings particles above 3 in. in size may consist of a lump of coal adhering to a lump of shale, but they are seldom truly intergrown particles. Intergrown particles are not often found except in the coal below 3 in., and the quantity generally increases in the smaller sizes down to about $\frac{1}{4}$ or $^3/_{16}$ in. They are more commonly found in the nut sizes of hard coal than of soft coal, and the size at which it becomes more economical to install mechanical cleaning plant is larger for hard coal than for soft coal.

In this paper present methods of cleaning coal mechanically will be described as briefly as possible. The factors chiefly to be considered in choosing a process for coal cleaning will then be stated.

Coal-Cleaning Processes

In cleaning the coal that is too small to be cleaned economically by hand picking there are a number of limitations that must be imposed upon the plant and methods employed. Thus the plant must be cheap to install, operate, and maintain; the methods and plants used in chemical engineering generally are too expensive to use for coal cleaning, where 250 tons per hour is not an unusual throughput, and the refinement of which such plant is capable is neither required nor justified. The plant must also be capable of efficient operation with unskilled labour, and the method should not be one requiring precise adjustment or any quantity of consumable materials.

It would be inconvenient to describe all modern processes for coal cleaning in a single paper, and the description here is confined to stating the chief features of the principle processes, their respective advantages and disadvantages, going into detail sufficiently only to enable the operator to judge whether or not a certain process is worth consideration for his purpose. Fuller details of all processes can be found elsewhere ("The Cleaning of Coal": Chapman and Mott, 1928, London) and from the companies concerned. For a comparison of coal-cleaning processes from the practical and operating points of view, a paper by Chapman and Wheeler (*J. Soc. Chem. Ind.*, 1927, 46, 229T.) should be consulted.

The Baum Jig Washer. In all modern jig washers the coal is passed on to a perforated surface and intermittent upward currents of water are made to flow through the bed, causing the coal to accumulate in the uppermost layers. A downward flow of water through the bed between the upward currents is detrimental and is prevented as far as possible.

In the Baum jig the washbox is U-shaped and is divided into equal parts by a central longitudinal partition extending a short distance below the surface. On one side of the partition is placed the sieve on which the coal is washed. The upward currents are created by an air pressure applied to the surface of the water in the second compartment of the wash-box. The air is admitted by a series of valves placed in line and parallel to the central partition and the air pressure causes water to pass from the air compartment into the sieve compartment and through the bed of coal.

The raw coal is fed in a stream of water at one end of the sieve and is carried forward over the sieve in a direction parallel to the central partition. The heavy shale rapidly falls to the bottom and is removed through an opening at the rear end of the sieve, the sieve being inclined backwards to facilitate the passage of the shale towards the opening. The coal travels forwards and is gradually stratified more or less completely according to density, so that the clean coal passes over a wall at the forward end of the sieve and the dirt can be removed through a valve (or gate) at the foot of the wall. The dirt removal valve may be open continuously or may be operated intermittently. More regular washing results are obtained if the refuse discharge is continuous. The small dirt falls through the openings in the sieve into the body of the wash-box and is removed by a screw conveyor. All the dirt is collected in refuse elevators and the clean coal passes by a shoot to de-watering screens.

Water enters with the raw coal and overflows with the washed coal; additional water is admitted continuously into the body of the wash-box and minimises the harmful effects of the slight downward current that occurs when the air pressure is released.

The usual practice is to feed unsized coal below about 3 in. into a "primary" wash-box. The washed coal from the primary box is screened and the coal below $\frac{3}{8}$ in. is rewashed in a second box.

The Baum jig has been more widely adopted in Great Britain than any other washer, though in Germany it has not been installed so extensively as other types of jig. It is especially

suitable where large throughputs are required without sizing and without any extreme requirements as to efficiency. It is easy to control, but the power and water requirements are rather high. Because the fine dirt passes through the sieve and remains for some time in the hutch, considerable quantities of dirty slurry are produced. A separate middlings fraction cannot be obtained without a considerable sacrifice of efficiency and the cleaning of coal below $\frac{1}{8}$ in. is not very satisfactory unless it is rewashed separately.

Miscellaneous Jig Washers. In jig washers other than the Baum, pistons or plungers are used to create the upward water currents. The wash-box is divided into two compartments, as in the Baum, one containing the plunger and the other the sieve on which the bed is supported. Many jigs, such as the Coppée and the Lührig, are "cross" jigs, the coal travelling in a direction perpendicular to the division plate between the compartments, instead of parallel to it, as in the Baum and Humboldt, which latter are called "flow" jigs. When washing fine coal in the Lührig and Coppée jigs a bed of feldspar is placed on the sieve to minimise downward currents. The feldspar acts as a false bed and prevents coal passing with the fine dirt to the bottom of the wash-box.

In German practice cross jigs have been widely used in recent years, though they have been less used in France and Belgium. In America a number of jigs with movable sieves are used, the sieve with coal resting on it being raised and lowered in the water to produce the currents through the bed. This crude method has not been used in Europe for many years.

With many jigs other than the Baum the coal is sized before washing, but there is no evidence that this practice increases the efficiency. The evidence rather suggests that washing before sizing is more satisfactory. Preliminary sizing complicates the plant, increases all the costs, and makes supervision more difficult. Plunger jigs are more difficult to control and adjust than jigs of the Baum type, wherein the water is actuated by compressed air.

The Rheolaveur Washer. The Rheolaveur is a scientifically designed trough washer. The coal is introduced into a stream of water flowing down a steeply inclined trough, in which stratification according to density is rapidly produced. The inclination of the trough is then reduced and the particles are deposited on the floor of the trough in the order of density, the heaviest being first deposited. The lowest layers are removed through apertures in

the floor of the trough, the apertures being enclosed by rheo-boxes. The rheo-boxes (or rheolaveurs) are fixed to the underside of the trough and an upward current flows from them into the trough to control the nature of the particles removed.

The number of troughs and of rheo-boxes attached to the troughs may be varied to suit the coal, and the number is greater the smaller the coal under treatment. In a complete washery coal under 4 in. is passed without sizing into a two-trough installation. In each trough are two rheo-boxes. The material discharged at the first rheo-box of the first trough is delivered to the second trough for re-washing. The first rheo-box in the second trough rejects the refuse and the other products of this trough can be collected as middlings and can be used separately or be returned to the first trough and re-washed, after or without crushing. The material near the end of the first trough consists of almost pure coal and the second rheo-box in this first trough removes any remaining dirt, together with some coal. This fraction is returned to the cycle and re-washed.

When all sizes of coal below 4 in. are washed in this way, the fines below $\frac{3}{8}$ in. are usually screened out and re-washed in a fines washer. In this installation three or four troughs are used with as many as twenty or more rheo-boxes. If necessary the smallest sizes (slurry) can be further washed in a separate installation.

The Rheolaveur is the only washer able to wash nuts, fines, and slurry, and the ease with which the number of troughs and rheo-boxes can be varied renders it the most adaptable of all washers. The only moving parts are the rewash elevators and an automatic valve in the primary or nut coal washer. The power and water requirements are low. The initial and operating costs are lower than with most other types of washer, and results suggest that it is more efficient. Indication of its general applicability is provided by the fact that it has been erected in greater numbers than any other washer during recent years.

The Draper Washer. In the Draper washer the raw coal is fed into a vertical tube in which a fairly rapid upward current of water is made to flow. The coal is propelled upwards in the current, but the dirt is not supported by the current, and sinks. The upward current is introduced tangentially, giving it a helical motion. The washer is probably the best of upward current washers, but it has not hitherto proved popular, nor is it likely to do so, because of the necessity for close sizing before washing

and the small capacity of each unit (especially on fine coal). The power and water requirements are high, but the efficiency is high, and slurry can be cleaned with considerable success.

The Chance Washer. The Chance washer has not been erected in Europe, but it has achieved considerable success in the anthracite fields of the U.S.A. It may also be used for washing bituminous coal. The separation is effected by a current of a fluid mixture of sand and water flowing upwards in a conical vessel. When the mixture is maintained in a constant proportion it behaves as a liquid of fixed specific gravity, and the effective specific gravity can be varied from about 1.3 to 1.8 to suit the coal to be washed. Because the effective specific gravity is made to approximate to that of the particles to be floated, the range of sizes that can be treated in one operation is much greater than when an upward current of water alone is used.

In practice, coal from 4 in. to $^3/_{16}$ in. is washed without sizing. Coal below $^3/_{16}$ in. cannot be washed because the current of water required to suspend the sand grains is too high to permit small dirt particles to sink easily through the fluid. The sand is recovered from the washed coal and from the refuse by spraying them with water on jigging screens.

Each washing cone has a very high capacity and the process is cheap to install and easy to operate. The operating and maintenance costs are rather high because of the loss of sand and the abrasive action of the sand-water medium. The convenience of treating unsized coal is largely offset by the inability to clean coal below $^3/_{16}$ in.

Concentrating Tables. A number of makes of concentrating tables have been used for coal cleaning, the principal makes adopted being the Diester-Overstrom in America, and the H.H. (or Overstrom Universal) in England.

The coal is fed on to a riffled surface inclined downwards across its width and usually slightly upwards along its length. The riffles extend along the whole length of the surface and the deck is vibrated to and fro in a direction parallel to the riffles. This reciprocating motion is made to reverse rapidly from a forward to a backward direction, so that the particles in contact with the surface are jerked forwards along the table.

A current of water flows across the table and washes the lighter particles over the riffles. The heavier ones sink to the lower layers and are jerked forwards between the riffles to the end of

the table. By adjusting the height and general arrangement of the riffles the material is spread horizontally into a thin layer which gradually increases in specific gravity around the edges of the table.

Different makes of table differ in the means of producing the differential motion and the arrangement of riffling. The H.H. table has the simplest actuating mechanism, but the shape and riffling of the deck of the Deister-Overstrom give it a higher capacity.

Concentrating tables are best adapted to cleaning coal below about $\frac{5}{8}$ in., but can be used for sizes up to $1\frac{1}{2}$ in. Preliminary sizing of the coal is required, and operating difficulties are experienced with a coal of variable quality. Tables are cheap to install, but the efficiency is frequently low and the vibration requires that they be housed in a rigid building. They are perhaps best adapted for slurry washing, and one table would probably be sufficient for the majority of British washeries. The recently-introduced Broadway table, which has a lateral rocking motion in addition to the longitudinal vibration, is specially designed for this purpose.

Froth Flotation. The separation of dirt from coal by froth flotation depends upon the different wettabilities of coal and dirt surfaces. When suitable oils are added to water in the optimum quantities a stable froth can be produced by agitation, and coal can be more readily attached to the bubbles in the froth than the more readily wetted dirt. The coal is thus floated to the surface, and the dirt sinks.

Coal cleaning by froth flotation has been practised to a considerable extent on the Continent, but its use is limited to coal below $^1/_{10}$ in. and the results obtained in industrial operation are not especially good. The strong retention of water by the washed coal renders drainage very difficult and the operating costs are high.

Many types of process have been devised, but those chiefly used are the Minerals Separation and the Kleinbentinck. The Elmore process has been widely used in ore dressing. It is said that with the new Elmore process coal up to $^3/_{16}$ in. can be washed and the concentrate can be drained to about 15 per cent. of water. The operation is conducted under a vacuum which can also be used for de-watering.

Pneumatic Separators. Pneumatic separators resemble concentrating tables to the extent that both use a riffled deck on which the coal travels transversely over the riffles and the dirt is trapped between the riffles and propelled in a different direction by the reciprocating motion of the deck. Instead of using a current of water across the table, however, a blast of air blows through the previous deck of the table and stratifies the particles.

The riffles can be tapered and variously arranged, and the strength of the air current can be varied at different parts of the surface. The early separators required close sizing of the feed (in the theoretical ratio for separation in an upward current of air), but the improved arrangement of riffling and the air-directing devices have enabled the size ratio to be increased to about 4.1 on the Wye separator. Higher ratios may be possible with some coals, and it is claimed that all sizes of coal from 3 in. to 0 can be treated on the Peale-Davis table, a claim that remains to be substantiated under British conditions.

Pneumatic separators are expensive to install, and the results obtained hitherto suggest that the efficiency, especially on fine coals, is not so high as has been hoped. In operation the tables require considerable attention, especially with a coal of variable quality. The separation is visible to the eye, however, and this enables irregularities to be more easily noticed.

The dust from the coal must be collected separately, and no entirely satisfactory means of collecting the very fine particles has been devised, nor is the collected dust a readily marketable commodity.

Spiral Separators. On spiral separators coal and dirt are separated by taking advantage of the different amounts of centrifugal force acquired by the particles as they slide down a vertically-disposed spiral thread. The coefficient of friction between the dirt and the metal of the thread is usually greater than that between the coal and the thread. Coal particles are thus less retarded by friction than dirt particles, and in sliding down the thread they can acquire higher velocities. The centrifugal force causes them to pass towards the rim of the thread (which is inclined upwards from the axis) and pass over the edge into a collector, leaving the dirt particles sliding down near to the axis. Various modifications of the surface are introduced to increase the efficiency.

It is said that, at one time, 22,000 spiral separators were in use in the U.S.A., but many of these have been discarded. Only a limited number of coals, chiefly anthracites, are suitable for treatment on spiral separators, coal below $\frac{3}{8}$ in. cannot be treated, and coal above $\frac{3}{8}$ in. must be closely sized. The initial cost is high, but the operating cost is low, there being no moving parts in the actual separator. They are inefficient, require frequent adjustment, and the coal is severely fractured.

Miscellaneous Processes. In addition to the processes and types of process described there are a number of others which are still in the undeveloped state. These are the Raw, Berrisford, Clean Coal, Dry Coal Cleaning, and Kirkup processes.

The Raw process utilises air pressure in a novel way by causing a state of fluidity in a bed of coal, thus enabling stratification strictly according to density to take place. Unsized dry coal can therefore be cleaned, and the results obtained in three commercial plants that have been working for a considerable time are very promising (*vide* paper by Raw and Ridley).

In the Berrisford process closely-sized particles of coal and dirt are allowed to fall on to an inclined plane of glass. The coal bounces down the plane and over a gap, whereas the dirt fails to bounce and slides down the plane and falls through the gap. The process is extremely cheap to install and operate, but its utility seems to be limited and the loss of coal in the refuse is high.

The Dry Coal Cleaning Co.'s process also depends, among other properties, upon the different resiliences of coal and dirt. The dry, raw coal is fed on to an inclined and vibrating table. The dirt is concentrated against the end wall, which is inclined to the direction of vibration, and the coal spreads out in a layer behind it. The dirt is screened and the small sizes are re-treated on a similar table. The efficiency of the process in commercial operation is doubtful, and its application is likely to be greatly limited by the small capacity of each unit and the considerable weight of appliance to be vibrated for so small an output.

The Clean Coal Co.'s process may be regarded as a large-scale float and sink test, the dust being removed from the coal before treatment. The separating medium is calcium chloride, which gives solutions of specific gravity up to 1.4. The coal is skimmed from the surface and the dirt removed from the base by an elevator. Each fraction is washed with water and drained. The loss of calcium chloride is minimised by concentrating the bulk of the

weak liquor, but there must still be some loss of the salt. The cost of operation is likely to be excessive and the wastage of water may be an objection in other cases.

In the Kirkup process the coal is fed into a trough with a perforated bottom, beneath which is an air chamber connected to a rapidly rotating pulsator and fan. The coal is stratified and the layers are separated at the end of the trough. The process has the advantage of working without vibration, but with the existing design the efficiency is not as high as is required.

The Choice of a Cleaning Process

The choice of the most suitable process to employ to clean small coal is a matter for careful thought. The choice must frequently be influenced unduly and unfortunately by the question of first cost, especially in the present state of depression when credit is restricted, but when a company is in a position to install the most suitable process, as distinct from the cheapest, the principal guiding factors should be :—

1. The market for the coal.
2. The effect on the total cost of production of the marketable product.
3. The circumstances in which the process must be operated.

The Market for the Coal. According to the market in which the coal is to be sold, the colliery officials must consider whether only the nut coal or only the fine coal need be cleaned, or whether both nuts and fines must be cleaned. Nut coal is cheaper to clean, the difficulties of slurry (or dust) disposal scarcely arise, and the efficiency is higher than in cleaning fines. In many of the Midland districts of Great Britain the large coal and nuts are sold largely for domestic purposes and gas manufacture, and must be cleaned before they can be sold, but it is frequently unprofitable to clean the fines because of the small margin between the price of washed and unwashed slacks. This may only be a temporary state of affairs, but where boiler coal or small coal for general manufacturing purposes can be sold without cleaning, the question as to whether the cleaning of the fines is or is not profitable is worth investigation. There are at present many washeries in which nuts and fines are both washed and where the fines are non-coking and contain about 15 per cent. or less of ash. In many of these cases it would pay to shut down the fines washer

and to remove the fines before washing the nuts. The unwashed fines could be sold to better advantage (taking account of the loss of output on washing) than the washed slack.

In other districts where the coal is a coking coal, for example in Durham, it is often only necessary to clean the smaller sizes, for the nut sizes can be crushed and then cleaned prior to use as coking slack. With some coals the nuts are clean enough for sale without preparation (other than sizing).

The third alternative, to clean both nuts and fines, is the most common in Great Britain as a whole. It is easy of accomplishment in such washers as the Baum and Rheolaveur, in which large quantities of coal from 3 or 4 in. to 0 are often washed in one box, or trough, only the fines through, say, $\frac{3}{8}$ in., being rewashed. In such washers the expense and inconvenience of sizing before cleaning are eliminated, and such sizing as the market requires can be accomplished more accurately after than before washing.

Market requirements also influence very considerably the question as to whether a dry or a wet process should be chosen. Wet processes are more efficient, but for some purposes the water in washed coal is detrimental. Unscreened Durham gas coal, for example, is carbonised in horizontal retorts, and dry cleaning is almost essential. On the other hand, water is very frequently added to coal before use, and the small amount of water retained by nut coal after washing is seldom disadvantageous to its sale or use.

The Effect on the Cost of Production. With modern processes, such as the Baum and Rheolaveur, the costs for operation and maintenance of the cleaning plant should not be more than 3d. per ton of raw coal for a plant dealing with 100 tons per hour, but the absolute cost depends very largely upon local conditions, such as wages, rates, the cost of power, and whether the washer is working one, two, or three shifts. In general there is little to choose between the two processes, and there is little doubt that, reduced to a uniform basis, they are the two cheapest. Other processes requiring sizing are more expensive, not only on account of the need for screens, but also because a larger number of units must be provided. Concentrating tables and pneumatic separators are more expensive to operate for these reasons, and the vibration must make them dearer to maintain. It is difficult to bring froth flotation into the comparison because of the different

class of coal treated, but the power consumption is necessarily heavy and the total costs appear to be high.

A comparison of published costs of operation is frequently deceptive, and to be strictly comparable the amount of inside and outside labour, the cost per unit of power, whether power consumed includes conveying to and from the washery, etc., must be stated and wages and other costs must be calculated on a uniform basis.

By comparison with the costs for operation and maintenance the capital charges for coal-cleaning plant are high. The capital cost for a complete plant with building is usually between £10,000 and £25,000 for a plant to treat 100 tons of raw coal per hour. Allowing 10 per cent. interest on capital and capital redemption in fifteen years, the capital charges amount to between 1.21d. and 3.03d. per ton of coal washed. To this must be added the cost of rates, taxes, management, etc., which are common to all processes.

The capital cost of the cleaning plant varies considerably according to requirements, and special circumstances arise in almost every case. A strict comparison is therefore impossible, but it is usually considered that, in capital charges, the Baum washer and pneumatic separators (Wye type) are more expensive than most other processes, and that of processes that have been proved commercially successful, the Rheolaveur is about the cheapest of wet washers.

An additional factor to be taken into account in assessing the cost of cleaning coal by any process is the loss of coal in the refuse and the amount of breakage during cleaning. Processes such as that proposed by the Clean Coal Co. should ensure a smaller loss of pure coal in the refuse than concentrating tables and pneumatic separators, the efficiency of which is especially subject to fluctuation with variation in the raw coal. On the other hand, simple flotation at a specific gravity of 1.4 would result in the loss of all the valuable middlings particles of specific gravity 1.4 to 1.6. These, whilst increasing the ash content of the clean coal by a mere 0.5 per cent., might increase the yield by 2½ per cent.

The Circumstances in which the Process must be Operated. The factors that must be taken into account (other than those already dealt with) in deciding which process best meets an individual need may be summarised without discussion. These factors are :—

1. The nature of the existing plant (if any).
2. The space available.
3. The degree of cleaning and sizing required.
4. The nature of the raw coal.
   (*a*) Per cent. of fine dust.
   (*b*) Friability.
   (*c*) Hygroscopic condition.
   (*d*) Chemical nature of the impurities
5. The regularity of the seams.
6. The throughput required.
7. Water supply and requirements.

The Cost of Coal Cleaning

The costs of operation and maintenance and the capital charges for coal cleaning have already been discussed in connection with the choice of a coal-cleaning process. The chief cost to a colliery company of cleaning its coal, however, is not connected with the nature of the process used, but it is common to all processes, and it arises because some of the pit's output, for which the costs of winning, loading and winding have already been incurred, must be discarded. An additional cost is represented by the coal remaining in the refuse. In many cases this amounts to 3 or 4 per cent. of the refuse, and may correspond to a loss of nearly 1d. per ton.

In general, to reduce the ash content of the coal to about 6 or 7 per cent., the rejected material will contain about 60 or 70 per cent. of ash, and the output must be reduced by about 1½ per cent. for every 1 per cent. ash reduction. If the coal is to be cleaned to a lower ash content, the refuse must consist of material with a lower ash content than 60 to 70 per cent. and the loss of output will be still greater for each 1 per cent. reduction in ash content.

The following example may be taken as typical of the case at a large number of British collieries. The coal is actually a South Yorkshire coal with the following float and sink analysis :—

S.G.		Weight per cent.		Ash per cent.
< 1.35	...	70.9	...	2.0
1.35-1.40	...	4.5	...	11.0
1.40-1.50	...	3.9	...	14.3
1.50-1.60	...	2.9	...	19.6
> 1.60	...	17.8	...	67.0
Total	...	100.0	...	15.0

From the washability curve of this coal the minimum loss of output may be determined, and this is shown in the following Table :—

Ash in washed coal, per cent.	Minimum loss of output, per cent.
8.0	9.0
7.0	10.7
6.0	12.4
5.0	14.0
4.0	16.6
3.0	21.0
2.0	29.1

To reduce the ash content to 8 per cent. the loss of output is only 1.3 per cent. per 1 per cent. of ash reduction. To reduce the ash content from 8 to 6 per cent. the additional material that must be rejected amounts to 1.7 per cent. per 1 per cent. ash reduction. Washing from 6 to 4 per cent., each 1 per cent. reduction of ash means the loss of 2.1 per cent. of material, from 4 to 3 per cent. the additional loss is 4.4 per cent., and from 3 to 2 per cent. 8.1 per cent.

It is obvious from these figures that the cost of producing clean coal, as influenced by the loss of output, increases enormously the greater is the reduction in ash content of the coal, and this fact should be borne in mind by consumers who demand very clean coal. Unless the consumer is prepared to pay a substantial premium for a reduction of ash from, say, 6 to 3 per cent., it will be much against the producer's interest to offer 3 per cent. ash coal. It is, indeed, not to the producer's advantage to wash coal more than he is actually compelled to do, and the cost of washing increases very rapidly the lower the ash content of the washed coal.

RÉSUMÉ

La grandeur des "petites houilles" est fixée par l'auteur comme celle où il se trouve plus avantageux à nettoyer les charbons d'une manière mécanique que de faire disparaître les schistes de main.

Tous les procédés modernes employés pour nettoyer les ' petites houilles" sont décrits en peu de mots par rapport à leurs avantages et leurs désavantages

respectifs. L'auteur énumère ainsi les faits qui méritent la plus grande considération dans le choix d'un procédé pour le nettoyage des charbons:—

1. Le marché destiné aux charbons.
2. L'effet sur les frais totaux des produits vendables.
3. Les circonstances où il faut que le procédé soit appliqué.

Ces faits sont considérés en quelque détail et la question du prix du nettoyage des charbons fait le sujet d'un examen rapide.

THE CLEANING OF COAL BY FROTH FLOTATION

THE INSTITUTION OF MINING ENGINEERS

E. EDSER AND P. T. WILLIAMS

Paper No. C5

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INTRODUCTION—OPERATION—ECONOMIC CONSIDERATIONS FOR THE IRON AND STEEL INDUSTRY

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RÉSUMÉ

Introduction

Methods of cleaning coal which depend on differences of specific gravity are well known, and have been practised successfully for many years. They are suitable only for coarse material; jigs cannot be used successfully for cleaning coal of less than 1 mm. in size, and tables are useful only for material over 0.3 mm. in size. It is generally admitted that the presence of very fine material in the jig circuit is undesirable, and some authorities contend that it is highly detrimental to efficiency; in many cases, American practice has been to remove the fines from the dry raw coal, jig the coarse sizes and add the untreated fines (below 4 mm.) in a dry state to the drained, washed product. As a general rule, however, the fines contain so much dirt that their addition to the washed coal would increase the ash content of the product above the market requirements.

During recent years, numerous patents have been granted for methods of cleaning fine coal by froth flotation. This process is applicable to all sizes less than about 3 mm., and therefore forms the natural complement of gravity methods used for coarser sizes. The efficiency of the froth flotation process is

maintained however small the particles may be; it has proved successful on pond slimes of impalpable size.

Operation

The cleaning of coal by froth flotation involves the following conditions :—

(*a*) The material to be treated is mixed with sufficient water (say four times its weight) to form a mobile mixture.

(*b*) Finely divided bubbles of air are disseminated through the aqueous mixture. Particles to which a sufficient number of bubbles attach themselves will rise to the surface, where they may remain supported in the resulting froth. Particles to which bubbles do not attach themselves sink to the bottom of the containing vessel.

It has been found that minute bubbles attach themselves readily to particles of bright coal, but not to particles of shale. Consequently bright coal and substances like shale in an aqueous mixture can be separated by producing a sufficient number of minute bubbles of air therein. To float a ton of bright coal particles (s.g. 1.35), at least 260 litres of air, in the form of minute bubbles, must be attached to the coal particles, and to disseminate this amount of air through the mixture of coal and water certain conditions must be complied with. The air itself may be introduced into the liquid mixture from above by splashing or by vigorous motion of a mechanical agitator shaped like the propeller of a steamship; or from below, through porous earthenware or a permeable medium, such as canvas; or through an air pipe provided with an orifice in the region of reduced pressure of a mechanical agitator. The mere introduction of the air does not ensure that it can be disseminated in the form of minute bubbles; for this to be achieved, the properties of the water must be modified, preferably by the addition thereto of a small quantity of certain soluble substances, such, for example, as cresol, which diminish the surface tension of water.

The minute air bubbles will attach themselves readily to particles of bright coal. It is generally necessary, however, to float, not only the bright coal, but also "bony" or bastard coal of sufficient calorific value. The addition of a limited quantity of an insoluble oil, such as kerosene, will secure this end. Apparently the oil forms a film on the particles of greater calorific value in preference to those of lower value, and air bubbles attach themselves

to the particles whose surfaces are filmed; thus the addition of oil can be regulated so as to recover that part of the coal which is required, while the remainder is discarded. The amount of insoluble oil required (less than ½ Kg. per ton of coal) is so small, and it must be distributed over such a large surface, that it would scarcely suffice to produce a uniform mono-molecular layer over the particles that are rendered floatable. If material high in ash is to be excluded rigorously from the concentrate, a small addition of an alkali, such as sodium silicate, is useful, particularly when the coal is contaminated with fireclay. The flotation of fusain may be prevented by the addition of starch in small quantities (a few ounces per ton of coal).

In carrying the froth flotation process into effect on a commercial scale, the fine coal to be cleaned is fed with water into a chamber in which it is stirred vigorously by an agitator shaped like the propeller of a steamship. While the aqueous mixture is being agitated, the frothing agent (*e.g.*, cresol) and the oiling agent (*e.g.*, kerosene) are added and thoroughly mixed therein; creosote oil, which comprises both a frothing and oiling reagent, has also been used. About ¾ lb. cresol and ½ lb. kerosene per ton of coal treated will usually suffice.

Multitudes of minute air bubbles are formed and disseminated throughout the mass, which then flows into a second chamber where relative quiescence permits the coal particles to which bubbles are attached to rise to the surface and form a stable froth. The residues pass into a second agitation chamber where additional aeration is effected, followed by transference to a second froth-forming compartment, and so on. In general, a machine comprises six or more agitation chambers. About 3 H.P.hr. are required per ton of material treated. One labourer can control flotation machines treating 60 tons per hour.

The froth flotation process for cleaning coal is now extensively used on a commercial scale. A plant in continuous operation since 1924 at Bargoed, South Wales, treats fine coal below 2 mm. in size, containing about 22 per cent. ash, and produces a concentrate containing 4.5 per cent. ash and residues containing 70 per cent. ash. As a result of the success of this installation, a plant is now under construction at Bargoed to supply the needs of a new battery of thirty-five by-product coke-ovens of the latest type which will carbonise coal flotation concentrates exclusively.

Froth flotation provides a means of separating certain particles

from other particles in an aqueous mixture; when applied to the cleaning of coal, the procedure is determined by the character of the coal and the market requirements. If bright coal were contaminated merely with shale, a clean separation of the coal and shale could be effected. Most coals contain bony material of variable ash-content, and it is necessary to arrange the conditions of the flotation so that bony material containing more than a certain percentage of ash is not floated.

Before deciding on the flotation treatment to be employed, it is advisable to determine the characteristics of the coal to be treated by float and sink analysis. Mixtures of bromoform, carbon tetrachloride, and benzine, having specific gravities of 1.3, 1.35, 1.4, 1.5, 1.6 and 1.8, may be used with advantage. When the proportional weights of these fractions and their ash, sulphur and phosphorus contents have been determined, the character of the coal is known, and the maximum weight of a product of any desired grade of purity can be ascertained.

The flotation operation can be carried out so as to separate the coal into graded fractions, which can be combined as required so as to produce the most useful product.

Fine coal (1 mm.—0) from a coal mine in the Pas de Calais, containing 21 per cent. ash, was separated into fractions, first by the use of heavy liquids and then by froth flotation. The results obtained are summarised in the following tables :—

FLOAT AND SINK ANALYSIS

Weight of fraction per cent.		Ash per cent.
67	...	4
5	...	18.4
8	...	31.0
20	...	74.6

FRACTIONATION BY FROTH FLOTATION

Weight of fraction per cent.		Ash per cent.
68	...	5
5	...	19.6
7	...	31.0
20	...	72.3

When the flotation of fines has been carried out, as a complement to the cleaning of coarser sizes by gravity methods, the

flotation concentrates have usually been added to the washed coarse coal and drained in suitable bins, or the like. This procedure has been used very extensively; in Germany alone, about 1,000,000 tons of fine coal are cleaned by flotation annually and disposed of in this manner. The absence of clay and similar substances from the flotation concentrates facilitates drainage.

Flotation concentrates can be briquetted without preliminary drying. The concentrates associated with their own weight of water are heated to 60 to 80°C., and a mixture of tar and pitch, amounting to 3 to 5 per cent. of the weight of the coal, is added during agitation. The tar and pitch coat the coal particles with thin uniform films and intense flocculation or agglomeration is produced. The water can be squeezed out of the mass, and, on subjecting the agglomerates to a pressure of 2 tons per sq. in. in a mould provided with narrow slits for the escape of the water, excellent briquettes are produced. After standing for a few hours the moisture contained in the briquettes falls below 4 per cent.

This method of briquetting can be used to de-water coal concentrates that are to be used for coking with an improvement in the character of the coke. A coal from the Saar Valley, which, in ordinary circumstances, produces an inferior coke of a friable character, was briquetted in this manner and subsequently coked, with the result that a fine-grained, coherent coke, with a crushing strength of 161.7 Kg. per sq. cm., was produced.

Coal concentrates, as obtained from a froth flotation plant, are associated with about their own weight of water. They can be filtered and dried more readily than the fine coal from which they were produced, owing to the fact that clay and finely divided shale, which have been discarded, retain water with great tenacity. By the aid of vacuum filtration the moisture associated with flotation concentrates can be reduced to about 15 per cent. Vacuum filters have been developed on a commercial scale for the treatment of ore slimes, and remarkable success has been attained. In order to obtain like success in the filtration of coal the dimensions of the machine should be extensively modified. The coarsely granular character of the coal concentrates requires very rapid removal of water and the formation of a comparatively thick cake; consequently, the relative dimensions of the filtering area and the pipes that carry away the water require radical modification. Further, metallic cloth of 0.5 mm. aperture has

been used to replace the cotton twill generally used for ore treatment.

Coal containing 15 per cent. moisture is not suitable for coking under modern conditions. Direct heat driers have been operated successfully to reduce the moisture to 6 per cent.

The outstanding characteristic of froth flotation, as compared with other methods of cleaning coal, is that the concentrates are naturally produced in six or more fractions of graded ash-content, and these fractions can be combined to form a number of products to suit the market requirements. Unless full advantage is taken of the possibilities thus afforded, much of the usefulness of the process is sacrificed.

Economic Considerations for the Iron and Steel Industry

Many iron and steel producers control their supplies of raw coal, and in such cases it is inexcusable for the cleaning of the raw coal to be governed by the requirements of a maximum output of coke at a specified ash, sulphur and phosphorus content. The interest of the iron or steel producer demands the most economical production of pig-iron or steel, and this condition alone should govern the cleaning of the raw coal.

Mr. C. S. Gill, in a paper read at the Glasgow meeting of the Iron and Steel Institute, 1927, published the results of operating a blast furnace plant for two periods, each of five weeks, all conditions remaining constant except the ash-content of the coke. The results are shown in the following table :—

	Period I.	Period II.
Average ash in the coke, per cent. ...	12.15	9.76
Average weekly make of pig-iron, tons	3311	3819
Tonnage of No. 3 grade, tons	210	134
Percentage of No. 3 grade	6.34	3.51
Average pressure of blast, lb. per sq. in.	5¾	4¾
Increase in make, per cent.	—	15.4
Reduction in coke consumption, cwt. per ton of pig-iron	—	1.01

These results disclose the striking fact that 55 tons of additional ash in the coke used reduced the output of iron by 508 tons, from which it may be inferred that each ton of ash diminished the

output of iron by about 9.4 tons. Considering the heavy overhead charges inevitably incurred in smelting iron, such a reduction of output must have an important effect on the cost of production of the iron.

It is obvious that the introduction of ash into the furnace will generally diminish the output; the ash occupies space that otherwise might be occupied by ore and carbon, and, in general, its presence necessitates the use of additional fluxes that occupy still more space. The results published by Gill indicate that the advantages of using coke low in ash are much greater than would be anticipated from these considerations. The rapid combustion of the low-ash coke may produce a higher temperature in the zone of combustion and accelerate the rate of smelting.

It is worth while to analyse Gill's results so as to estimate the financial loss incurred by the introduction of each ton of ash into the furnace.

It is assumed that, in Period I, 24 cwt. of 12.15 per cent. ash coke were used to smelt each ton of pig-iron. The tonnage of coke used in Period I has been calculated on this basis, and the tonnage in Period II, which is less by 1.01 cwt. per ton of pig-iron, is calculated by difference.

	Period I Tons	Period II Tons
Coke used	3,973.2	4,390
Ash in coke	482.7	428.5
Carbon in coke (by difference) ...	3,490.5	3,961.5
Difference in quantity of ash charged	+54.2	—
Difference in quantity of pig-iron made	—	+508
Carbon used for output of Period I	3,490.5	3,434.5
Carbon used to smelt extra ash ...	+56	—
Carbon used for each ton of ash ...	1.033	

Thus, in Period I, compared with Period II, there was :—

A decrease in quantity of ash of 54.2 tons.
An increase in output of pig-iron of 508 tons.

The reduction in output of pig-iron due to each ton of ash in charge was, therefore, 9.4 tons.

The financial loss incurred was not limited to that due to the diminished output of iron; the addition of the ash also necessitated the use of extra coke and flux.

EXPENSE DUE TO 1 TON OF ASH

	Shillings
(1) To loss in output of pig-iron: 9.4 tons at selling price of pig-iron, less cost of raw material and handling, say, 16/- per ton	150
(2) To additional coke required to smelt 1 ton of ash, say, 1.15 tons at 17/6 per ton	20
(3) To coke-oven expenses on 1 ton of ash	12
(4) To additional limestone to slag the ash, 2 tons at 5/-	10
(5) To sulphur and phosphorus	Not estimated
(6) To increase in No. 3 iron	
(7) To increase in blowing costs	
Total ...	192

The expense incurred by adding a ton of ash to the furnace thus amounts to 192 shillings. No allowance has been made for expense due to items (5), (6) and (7).

The economic advantage of using low-ash coke will now be evident. In general, the reduction of ash in coke can only be attained by discarding those fractions of the coal which contain an undue amount of ash, and the economic conditions which should control the cleaning of coal for the production of metallurgical coke are that no fraction of the coal should be carbonised if its ash-content entails a smelting expense greater than the direct loss entailed by discarding that fraction. The following example will make this point clear:—

A Scottish coal, containing 15 per cent. ash, was cleaned by flotation, three fractions being produced. The amounts and ash contents of these fractions were as follow:—

Weight of fraction per cent.		Ash content per cent.
77.9	...	3.6
6.4	...	17.1
15.7	...	71.3

If fractions (1) and (2) were combined, 84.3 per cent. of the coal containing 4.7 per cent. ash would be utilised. Using only the first fraction, 77.9 per cent. of the coal containing 3.6 per cent. of ash would be utilised, and 6.4 per cent. of the coal containing 17.1 per cent. ash would be discarded. About 6 tons of this discarded material would contain a ton of ash, and the introduction

of this ash into the furnace would entail an expense of 192 shillings. The removal of one ton of ash could therefore effect a saving of 192 shillings. From this figure should be deducted the cost of the 6 tons of material and any charges it has borne, which together may be estimated at 60 shillings. Thus the net gain amounts to 132 shillings, which is equivalent to a saving of more than 1s. 6d. per ton of pig-iron produced. It should be noticed that this saving results from the reduction of the ash in the coal from 4.7 to 3.6 per cent. In practice, the advantage would be greater than this, since the 6 tons of 17.1 per cent. ash material could be used profitably for boiler firing.

Uniformity in the coal used for producing metallurgical coke is recognised as being even more important than its purity. Variation in the quality of the raw coal cannot be avoided; but the separation of a fraction to be used for boiler firing facilitates the maintenance of uniformity in the coking product.

Although these principles have not heretofore been used for the production of coke of very low ash content, they have been employed, using gravity methods, for many years on the Continent for the production of coke of standard grade, *i.e.*, 10 per cent. ash. Many inferior Continental coals contain only negligible fractions of low ash content, and low-ash coke could not be made from them. It has been necessary to separate graded fractions of these coals, and to utilise only the purer fractions, in order to make coke of 10 per cent. ash.

The purity of Durham coals affords opportunity for the utilisation of the same principles to produce super-coke with an ash content of 4 per cent. or less. From the flotation concentrates of Durham coal coke of 1.9 per cent ash has been produced.

In the case where a coal contains sulphur and phosphorus in undesirable quantities, the distribution of these substances in the various fractions should be determined so that the cleaning operation can be most profitably controlled.

Slack, as generally used for coking, includes all sizes below 10 mm. It would be advisable to separate sizes above 3 mm., as these can often be sold to better advantage in other markets. The material below 3 mm. could be treated by froth flotation for the production of coke.

Coke made from flotation concentrates is fine grained, uniform in structure, and yet burns readily. Its uniformity, combined with its strength, results in a minimum production of breeze.

One effect of the uniform texture and absence of cracks in coke made from flotation concentrates is that its average moisture-content is less than that of coke produced from coal cleaned by other methods.

A Cumberland coal that was cleaned by a gravity method and then coked produced 4.5 per cent. of breeze; after the substitution of flotation as the method of cleaning the breeze produced amounted to only 1.5 per cent. A South Wales coal cleaned by jigging produced coke with a crushing strength of 106 Kg. per sq. cm.; the same coal is now cleaned by flotation and the coke produced has a crushing strength of 176 Kg. per sq. cm.

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RÉSUMÉ

Le lavage des fines par flottage est accompli en mélangeant les fines avec de l'eau et en disséminant des bulles d'air menues à travers tout le mélange. Les bulles adhèrent à certaines particules, plus particulièrement à celles de charbon brillant, et les remontent à la surface où elles forment une mousse persistante. D'autres réactifs peuvent être ajoutés afin de modifier les surfaces des particules, et ainsi, ou bien faciliter ou bien annuler l'adhérence des bulles d'air auxdites particules. Par ce moyen on peut faire flotter non-seulement le charbon brillant, mais aussi des mixtes ayant une valeur calorifique suffisamment grande. Le procédé peut trouver son application à n'importe quelle matière au-dessous de 3 mm., et il réussit avec les schlamms les plus fins. Le charbon lavé est produit dans une série de fractions avec pourcentage de cendres gradué; ces fractions peuvent être combinées afin de former des produits qui se conforment au mieux aux besoins du commerce.

L'humidité qui accompagne le charbon flotté peut être réduite par filtrage à vide; l'application de chaleur est nécessaire pour obtenir un plus haut degré de séchage. Le charbon flotté peut aussi être briquetté sans séchage préliminaire.

Du coke ayant un pourcentage de cendres aussi faible que 1,9 pour cent a été produit avec du charbon flotté. L'emploi de coke à faible pourcentage de cendres assure des avantages importants dans la production du fer et de l'acier. Nous avons donné des preuves qui montrent que l'introduction d'une tonne de cendres dans un haut fourneau cause une réduction de 9 tonnes dans le débit de fonte en gueuses, ce qui signifie une perte monétaire marquée.

THE PRINCIPLES OF PNEUMATIC SEPARATION WITH A DESCRIPTION OF THE STATIC DRY WASHER

THE INSTITUTION OF MINING ENGINEERS

GEO. RAW AND F. F. RIDLEY

Paper No. C6

CONTENTS

INTRODUCTION—THE GENERAL PRINCIPLE HITHERTO APPLIED TO PNEUMATIC SEPARATION—NEW PRINCIPLE OF PNEUMATIC SEPARATION—THE STATIC DRY WASHER—CONCLUSION—APPENDIX BY PROF. G. R. GOLDSBROUGH—BIBLIOGRAPHY—ZUSAMMENFASSUNG

Introduction

The increasing demand for dry clean coal during recent years has stimulated investigation and invention in the field of pneumatically-operated separating machines. The art is by no means new. Numerous types have been devised for the dry treatment of metalliferous ores and recently some of these have been adapted to the treatment of coal.

The economic conditions of coal treatment are different from those governing ore dressing. The relatively low value of the coal and the large quantities to be treated require stringent conditions to be satisfied by the design and operation of the plant. As the reward for the improvement of the product is of an indirect character, it is essential that the necessary plant should not be subject to a prohibitive capital outlay or be expensive in running and maintenance costs. The conditions of colliery working also demand a plant of a robust and practical character, simple of control and not requiring such elaborate adjustment as is permissible in low-capacity plants.

Several methods have been developed to accomplish this separation without recourse to wetting the coal, but in these it has generally been sought to employ the principles adopted in water separation,

with the substitution of air as the differentiating medium. Reliance has been placed upon the motion of the air to produce the separating action.

Many pneumatic separators have been devised on these principles, usually taking the form of air jigs or vibratory tables operating on thin streams of material. Most separators of the air-jig type are unsuited for coal treatment. They have usually been designed to treat small quantities of finely comminuted material of a particular character, and are therefore too limited in their application. The vibratory type of table (*e.g.*, Sutton, Steele & Steele and Arms types) alone has so far found any general commercial application for coal treatment, and the limitations attendant upon the application of the principles underlying the operation of these types led to an investigation which has resulted in the development of the new process described in this paper and utilised in the Static Dry Washer. This process, though coming within the general classification of pneumatic separation, depends upon the employment of fundamentally different principles from those hitherto adopted.

The principles underlying the operation of the earlier type will first be discussed, and this will be followed by an account of the results of experiments with the new process.

Examination of the General Principles hitherto applied to Pneumatic Separation

(*a*) *The use of an air current.* As air and water are both fluids and capable of applying force, they can both be employed to achieve separation in the same way, though the different physical properties of the two fluids modify the effects. Both fluids, when in motion, exert force on obstructing surfaces, but whereas water exerts a considerable buoyant force on bodies immersed in it, the force of buoyancy is practically non-existent in air, thereby reducing its effectiveness as a separating medium.

In pneumatic separation as applied to the earlier types of machine the effects of fluid resistance are brought into play by subjecting a layer of the materials on a pervious support to the thrust of vertical air currents passing upwards through the bed so that the lighter particles are elevated or balanced while the heavier remain on the pervious surface. Those particles which are too heavy to be balanced by the thrust of a particular velocity of air current comprise the lower layer, whilst lighter particles which are balanced by the same current occupy the upper layer. Assisted sometimes

by mechanical vibratory motion and sometimes by gravity, the layers are separately discharged. The separation thus depends upon an initial stratifying operation followed by the mechanical operation of separating and removing the different strata.

The principle underlying the stratification is the same in all separating machines of this type, but the actual separation is accomplished by a variety of means employing different types of apparatus.

(*b*) *Theory of stratification by air currents.* When a body falls through a fluid under the influence of gravity, its fall is opposed by the eddy and frictional resistance of the fluid set up by the motion of the body. The resistance increases with the velocity of the body until a stage is reached when it has so high a value that the motion of the body is no longer accelerated. The resisting force then balances the effective weight of the body in the fluid. The body continues to fall with a uniform velocity, this value being named its "terminal velocity." Since the terminal velocity is determined by the magnitude of the fluid resistance, which, in turn, is dependent upon the relative motion between the fluid and the body, a current of the fluid flowing at the terminal velocity will present a like resistance to the same body when stationary. If this current be rising vertically the body will be balanced.

The velocity of fall ultimately attained by a falling body only represents the relative velocity between body and fluid when the size of the former is small compared with the confines of the latter, so that no upward currents of any consequence are caused by displacement of the fluid. When these conditions do not obtain, the balancing or terminal velocity is that which actually exists between the body and the fluid flowing past it.

Very little data of practical value have been available on the subject of the fluid resistance of air to moving bodies. The experiments and analysis of R. G. Lunnon,[1] have, however, now established the effects of this resistance, making reliable calculation possible.

Lunnon's experiments consisted in dropping spheres of different sizes and materials down pit shafts under accurate and favourable experimental conditions. The times of fall over measured distances were determined, and from these values, together with known data, the effects of the resistance of the air could be computed and the conditions of fall examined. It was shown from the experiments that the resistance of the air to the motion of spheres over the range of sizes used in the experiments (4 to $\frac{1}{8}$ in. diameter) was proportional to the square of the diameter and the terminal velocity

was proportional to the square root of the diameter times the density of any sphere. A formula (see also Appendix) was deduced by Lunnon for the actual value of the terminal velocity of any sphere within the range. This range is sufficiently comprehensive for the purposes of application to the subject of this discussion.

With very small particles the fluid resistance follows a different law, according to the recent investigations by Martin[2], the air exerting a relatively greater resistance. The effects with these very small particles will not be considered in this paper.

To stratify particles successfully by the application of the foregoing principles, it will be seen that since the thrust of the moving air is exerted against portions of the particles' surfaces, the areas of these surfaces are of account, and consequently, in order that pieces of coal may be stratified above pieces of stone, the sizes of all the particles must be confined within certain limits. If such is not the case large coal particles will remain at the bottom of the bed with the stone, and small stone particles will be carried to a higher level with the coal. This may be illustrated by considering two spheres resting on a pervious support and of the same diameter, one of coal of density 1·3 and the other of stone of density 2·6, exposed to a vertical air current. The current will exert an equal thrust on each particle. Suppose a velocity of air be applied which is just insufficient to balance the weight of the stone particle, the coal particle will then be lifted while the stone remains on the support. The weight of a sphere is proportional to the cube of its diameter, and as shown by Lunnon (*loc. cit.*), the thrust exerted by the air current is proportional to the square of the diameter. In order, therefore, to make the weight of the coal sphere in air equal to the thrust of the air current, its diameter must be increased two-fold. That is, the diameters of the spheres which are balanced by the same air current are inversely proportional to their effective densities. The coal is now no more affected by the air current than the stone and will remain beside it on the pervious support. Similarly, if a velocity is applied which will just balance a sphere of coal, the diameter of a sphere of stone which will be equally balanced will be half that of the coal. If it were any less than this, the stone would be raised above the coal. Thus the diameter of spheres of coal and stone which are balanced by the same velocity of air current mark the limits of size between which proper stratification by this method can be effected, and these limits are such that the diameter of any coal sphere must not be more than twice that of any stone

sphere, that is, sizing in a 2 to 1 ratio must precede the stratification.* If this ratio is not adhered to, accurate stratification is not obtained and, in practice, the materials must therefore be subjected to a sizing operation either beforehand or on the table.

To accomplish the balance of particles the air must pass them at a speed equal to the terminal velocity. Lunnon's determination of these velocities leave their values, and consequently those necessary in practice, no longer subject to theoretical assumption as has necessarily been the case in the past. Where determinations have been attempted[3], it was usual to assume that a head of pressure which is equivalent to the weight of a particle would generate a velocity sufficient to support it. This assumption involves the bringing to rest of the air in its application to the particle, an assumption which is manifestly incorrect. Lunnon's results, on the contrary, show that a velocity is required which is equivalent to a much higher pressure than is given by this assumption.

In the Appendix Dr. Goldsbrough applies Lunnon's formulae to an analysis of practical operating conditions and shows how the actual values of air supply and pressure may be computed. It will be seen from this analysis that instead of the pneumatic operation of these separators being complex and indeterminate in character, as has generally been believed, the process is so straightforward that theoretical principles may be applied in practice with almost mathematical precision.

Although the stone and coal to be separated on the tables are not spherical, these general principles are sufficient to explain the mode of operation. The diameters of the spheres may be replaced by the sized dimensions of the particles of stone and coal, such as would be determined by passage through sieves.

It will be noticed that the effect of size on the pneumatic stratification is entirely due to differentiation by motion of the air. If water is used as the stratifying medium, only the weights of the particles remaining unbalanced by buoyancy require to be

*A general rule for any fluid and pair of spheres, if the resistance follows the square law, is as follows:—

$$\frac{d}{d_1} = \frac{\epsilon_1}{\epsilon}$$

where d and d_1 are the diameters of the spheres and ϵ and ϵ_1 are their effective densities.

The effective densities of coal and stone in water are ·3 and 1·6 respectively, and the ratio of sizes is then

$$\frac{1{\cdot}6}{0{\cdot}3} = 5{\cdot}3$$

supported by water currents. The particles, therefore, do not require to be sized within such close limits.

(*c*) *Application of the principle of terminal velocity.* In the operation of pneumatic separators depending on these principles, the sized materials are usually spread out in a relatively thin layer on a pervious surface arranged above a chamber which is connected to an air supply. An air pressure causes air currents to flow through the bed around the individual particles at a velocity dependent upon the pressure. If this velocity is made equal to or slightly greater than the terminal velocity of the coal particles, they will be balanced or elevated whilst the stone will remain unaffected and stratification will result.

In order that the coal particles may be balanced by the air currents, the air must have free passage about them or the necessary velocity cannot be produced. This condition is realised in an open bed of sized particles which allows the air to flow freely through the orifices in the bed at the terminal velocities of the particles, when the required pressure is applied from the chamber below the layer of coal and stone. The method of calculation of these quantities is given by Dr. Goldsbrough in the Appendix.

(*d*) *Mechanical separation subsequent to stratification.* The ultimate separation of the coal and stone stratified according to the foregoing principles is merely a matter of the mechanical design of the apparatus.

If the particles have been previously graded so that they all fall within the limits of size defined in 2 (*b*) this operation is straightforward and comparatively simple. It is usually carried out on a machine of the well-known S.J. type.

Alternatively the degree of presizing of the raw coal may be diminished by the application of successively different strengths of air current in combination with particular features of mechanical design, principally of an experimentally determined character. Part of the sizing is then effected on the separator, instead of beforehand, and the separation is made with respect to size as well as density. Approximately equal sized particles are then discharged together at each point. Such a separation is exemplified in the Wye and the Peale-Davis separators.

New Principles of Pneumatic Separation

It will be evident from the foregoing that the influence of size on the separation is due to the use of the velocity of the air current. To be able to separate the materials without regard to the sizes of

the particles, velocity effects must be dispensed with and other factors relied upon. The foregoing principles can, therefore, never lead to a separation which is independent of size and depends only upon density.

It was principally the difficulties engendered by this dependence of the separation upon the sizes of the particles which stimulated the investigations now to be described. The possibility of achieving separation without the use of air velocity was the chief object of the research.

(*a*) *Results of experimental research.* The stratifying influences of air pressure on beds of coal and stone were examined under various conditions and several effects were observed.

It was found that when a closely packed "piston-like" bed of coal particles of mixed sizes (*e.g.*, 1½ in. to 0) on an oscillating pervious support was subject to air pressure from a chamber below the bed, different results were obtained with different values of pressure. At a certain critical value of pressure the bed became distended and assumed a "fluid" condition of a "viscous" character. Under these conditions stone particles of widely varying sizes placed on the surface sank slowly through the bed and stratified below the coal.

Below this pressure the bed remained inert except that the finer material riddled through to the bottom of the bed, due to the oscillation of the support. Immediately the critical pressure was exceeded, the fluid conditions broke down, and "piping" or "boiling" of the bed developed. This took the form of local ruptures or disturbances of the bed in which the smaller material rose to the surface and was even projected above the bed if the pressure was still further increased.

This critical pressure evidently represented a condition of equilibrium in the bed of coal and further tests with beds of various depths and of other materials showed that it had a definite value depending only upon the bulk density of the materials and the depth of the bed. For coal, this pressure was ·67 in. water gauge for each inch depth of bed. This pressure was registered in the air chamber and also immediately above the pervious surface at the bottom of the coal bed.

The graph (Fig. 1) shows the relation of the depth of bed of coal to the pressure required to be applied for the equilibrium condition. This relation of pressure to depth was maintained at all levels in the same bed, that is, the pressure diminished uniformly from the bottom of the bed to the surface.

Under the conditions governed by the critical pressure, there was

no sorting action of the particles with relation to size. The flow of air through the bed was found to be so slight as to be scarcely perceptible, small grain seeds and thin wood shavings resting on the surface.

(*b*) *Conditions of successful operation.* It is evident that a state of statical equilibrium in the bed is reached when the pressure at the bottom of the bed is equal to the weight of the bed. The bulk density of the unsized coal in the fluid bed is 42 lb./cu. ft. This is equivalent to a sp. gr. of ·67, which corresponds to the "Critical Pressure" as represented in inches of water gauge for each inch of depth of bed.

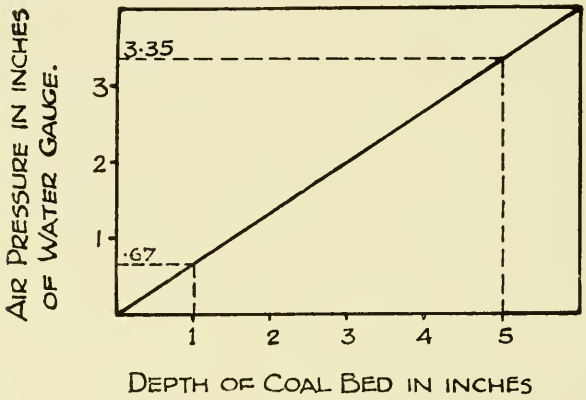

Fig. 1—Graph showing relation of Critical Air Pressure to Depth of Bed.

The examination of the pressures at different points in the bed shows that the diminution of pressure exactly corresponds to the load above that point and shows that there is no rapid expansion with the development of free air currents. The pressure thus acts statically through the whole thickness of the bed.

This operation of the pressure is made possible by the high resistance of the bed of unsized coal. The filling of the spaces between the larger particles by the smaller coal and the resultant close packing, prevents free egress of the air, the passages being so fine and tortuous that their resistance allows of only slow escape of air. This state of the materials is essential to the maintenance of a condition of statical equilibrium in the bed while subject to the action of the air pressure.

In contra-distinction to this condition of the bed, the open passages formed in the layers of sized coal on the earlier type of separators (*e.g.*, the S.J., Wye and Arms), result in immediate expansion of the air, so that the whole of its potential energy is converted into

kinetic energy with the formation of air currents of high velocity. These currents then provide the only means of supporting the individual particles according to the principle demonstrated in 2 (*b*).

If, with a closely packed bed, the critical pressure be exceeded, the bed of material will cease to exist as a unit and will break up into separate particles which are exposed to free air currents. The weakest points, which are where the interstitial spaces are largest, yield first, and there results a "burst" or "pipe" due to the raising of the smaller particles by the air current. If the critical pressure has only been slightly exceeded, the material round that point may fall in and damp down the air flow so that as this opening closes up a break-out at another weak place may occur. The general result is a boiling or turbulent condition of the whole bed. If the critical pressure is materially exceeded, however, all the smaller material is ejected and an appreciable opening is formed in the bed which becomes of much less resistance than the rest of the bed. The pressure, therefore, becomes occupied in driving air through the opening and the other parts of the bed become dead. The boundaries of the opening become further eroded as more material is ejected, the flow of air being only opposed by isolated particles. The free flow conditions described in 2 (*c*) then exist and only particles which have greater terminal velocities than the air supply is capable of delivering can remain on the perforated support.

By balancing spheres of coal in vertical air currents it was experimentally verified that the formulae and their application shown in the Appendix give close approximations to the actual pressures necessary to create velocities sufficient to support single particles and open layers of equal-sized particles.

These pressures are much higher than those necessary to induce the conditions of statical equilibrium which have been described. It will be seen by reference to the Appendix that the pressure necessary to create the terminal velocity of a 2-in. sphere of coal is 5·4 in. W.G. The pressure applicable to a 2-in. thickness of the closely packed bed under the statical conditions is 1·34 in. W.G. Under these latter conditions, a pressure of 5·4 in. W.G. would be sufficient for a bed 8 in. thick. It is, therefore, manifest that a much higher pressure than the critical value for statical application is necessary to stratify particles by the application of terminal velocity. Further, if the pressure applied be above this critical value by any amount, the conditions of statical equilibrium are invalidated and support of the particles can then only be accomplished by the application of their terminal velocities.

The application of the critical pressure required to produce the state of statical equilibrium in a packed bed is necessarily coincident with the passage of a certain small quantity of air through the bed, and it follows that this provides a velocity which must be the terminal or balancing velocity for some particle sufficiently small.

This velocity defines the limit of the smallest particles that can be stratified under the conditions ruling for the bulk of the bed, as particles which are so small that their terminal velocities are below this value will tend to be forced upwards through the bed. The value of this velocity depends upon the resistance of the bed to air flow and as the critical pressure is of a constant value depending on the bulk density of the bed, the higher its resistance the lower will be the leakage velocity and the smaller the particles which cannot be stratified. In practice this size is very small, for if the resistance were to allow the development of an appreciable flow of air, the statical condition could not be maintained owing to the sizing action of the air currents in the bed.

Experiments with average beds of unsized coal showed that very complete stratification could be accomplished. For example, it was found that particles of stone as small as 1/40 in. may be stratified in a bed of coal $1\frac{1}{2}$ in. to 0 in size. The top layers were quickly and completely freed from stone but further stratification was slower.

The analysis of the operation of this stratifying process is discussed in the Appendix, but it may be stated here that the elimination of size from the separation is due to the stationary character of the operation of the air pressure, whereas, as has been shown in 2 (*b*), stratification by motive effects of the air connotes a size influence. Under the conditions of equilibrium induced by the statical application of the pressure the stratification is only due to the fact that the fluid condition of the coal bed allows the unbalanced stone particles to sink and displace the coal. There is no direct displacement of particles of coal or stone by air.

A direct comparison between the two methods can be drawn in this respect. The terminal velocity or "dynamic" method of stratification is only applicable to accurately sized particles if the strata are to be arranged in order of density and can be operated with either a gas or an incompressible fluid. The "static" method of stratification is, on the other hand, only applicable to a closely packed bed of substantial thickness and of so high a resistance that the flow of air is damped down to relatively negligible value. This method can only be operated with a compressible fluid because

the bed is balanced directly by pressure due to the elasticity of the fluid. These conditions are satisfied by a bed of unsized coal containing considerable quantities of smaller particles. A bed of sized material would obviously not meet the requirements.

It was clear from experiments that the possibility of applying the process in practice would depend upon the maintenance of uniform thickness and resistance of the coal bed, maintenance of the correct pressure below and within the bed, and the maximum damping out of air currents through the bed. If the raw coal had not sufficient of the smaller particles in it to form a bed of high enough resistance to realise the necessary conditions, it would be essential to add suitable material to adjust the resistance before the process could be begun. The arrangement to be sought is one of maximum "fluidity" with the minimum escape of air. This condition is assisted by oscillation of the pervious support, which breaks down the friction between the particles and also helps to keep the thickness and resistance of the bed uniform.

(*c*) *The use of oscillating pressure.* The attempt at the more perfect realisation of these conditions in practice led to an investigation of the effects of a fluctuating pressure compared with one of constant value. It was early apparent that superior effects could be obtained both in the rapidity and quality of the stratification, if the pressure were made to rise and fall about the critical value in a particular manner depending upon periodicity, amplitude and phase. The quantity of air escaping was less under these conditions than under those of constant pressure leading to more complete stratification of the finer particles. There was less tendency for free air currents to develop at points of slightly less resistance. This indicates a great practical advantage in that less delicate manipulation of the table is required than when using a constant pressure.

The fluctuation of pressure is not to be confused with the production of intermittent blasts or currents of air such as were used in the old jigs. This was merely an increase and decrease of the volume of air passing through the bed. When the pressure is made to fluctuate in the correct manner, the passage of air is actually reduced and that which does escape does not issue in puffs but practically as a steady egression.

The character of the fluctuations of pressure and the physical factors governing the production of the optimum conditions have been the subject of considerable research and practical experiment. It was found that a particular combination of the duration of the

pressure impulse and the pressure generating the impulse gave superior results. Experiment showed that the frequency should be fairly rapid and at the same time the fluctuations of pressure should be of high amplitude. As the latter decreased with increased frequency, it was impossible to employ the very best operating conditions. This difficulty was ultimately overcome by the employment of the principle of resonance.

(*d*) *The application of the principle of resonance.* From a consideration of the conditions established by the application of impulses of pressure at the end of a closed chest (see Appendix), it will be readily understood that waves of condensation and rarefaction travel across the chest and are reflected from the opposite sides in directions depending upon the shape of the box. These waves travel with the velocity of sound and if the chest is of rectangular shape they will return to the source in a period of time depending upon the length of chest, and with a somewhat reduced amplitude due to the damping effect of the viscosity of the air.

If the impulses of pressure are timed to occur at exactly the same time as a wave of condensation arrives at the source, the waves will be reinforced and the maximum amplitude of fluctuation will be established. If, on the other hand, the impulses are not so synchronised, a number of waves will exist in the box at the same time, but out of phase with each other. The fluctuation of pressure is then destroyed and the pressure remains practically at the mean value.

It is not necessary to reinforce every wave, but instead, the recurrence of the impulses at periodic arrivals of waves at the source will maintain a high amplitude of fluctuation.

To examine the effects of irregularities in the shape of the air chest, sectional models were constructed in plasticine on a sheet of glass and filled with films of water. The influence of the walls was observed on the ripples generated by an electrically operated dipping needle. A rectangular chest was shown to be essential to the reinforcement of the waves. The effects of irregularities in the construction of the chest and table were examined by this method and, when necessary, the irregularities were removed.

The conditions were tested in practice on a full scale machine described later. The air chest was of rectangular shape with the end wall normal to its length, which was approximately that of the table. The resonant frequencies for the box were calculated by the method given in the Appendix, and the rate of application of compressive impulses was tuned to the frequency of oscillation of

the waves generated in the chest, by varying the speed of rotation of the pulsator.

When the system was thus tuned into synchronism, the effect on the operation of the separator was pronounced. The stratification, particularly of the finer materials and particles of intermediate density, was improved both in quality and rapidity. This improvement was accompanied by a more quiescent state of the bed, and with the egress of a smaller quantity of air than when employing constant pressure conditions. A further advantage was the greater ease of control of the separation. As long as the correct frequency of pulsation was maintained the table was practically automatic in its operation (apart from the adjustment of the amount of stone to be discharged).

It would appear that the avoidance of loss of amplitude due to the existence of waves out of phase with each other is of more consequence than the damping effects due to viscosity, which would not be expected to assume large proportions in air under such conditions. This means that the resonant condition is established, not so much by the building up of the amplitude by reinforcement, as by avoiding its destruction due to generating waves not in the correct phase.

(*e*) *Features of design essential to application of new principles.* The essential features of a separating table to operate according to the principles described, include the provision of sufficient area to allow the materials to stratify in travelling across it, means for separately discharging the different strata, and a pneumatic system suitable to the proper application of the air pressure. The material fed to the table must form a bed of high resistance to air flow and it must be fed on in such quantities as will maintain the bed at an even thickness over all the area exposed to the air pressure. It must, therefore, be fed at the same rate as it is discharged. The table itself must be designed to enable these conditions of uniformity to be maintained over all the table area which is subjected to air pressure. It will be appreciated that unless the design of table ensured that the coal bed formed a continuous and air-tight (apart from its own perviousness) piston, the separation would be liable to break down periodically, and much supervision would be required in practice. Since it is required that the air pressure should act statically in the bed, it is also necessary that as nearly as possible there should be no air current in the air chest, and for this reason it is desirable to have an air box of considerable volume so that directional effects of the air due to entry and egress are avoided.

These conditions dictated the general design of the machine, although the ultimate construction was the outcome of experience derived from designing and operating tables of varying form, all of which in a degree performed satisfactorily the function of stratifying and separating the materials. It was found possible to produce a complete plant which is sufficiently automatic in its operation and control to deal efficiently with the varying demands of full scale working over long periods without continual skilled supervision.

THE STATIC DRY WASHER

(*a*) *Description of Separator.* Illustrations of separators in practical operation at several collieries are given in the accompanying Figures.

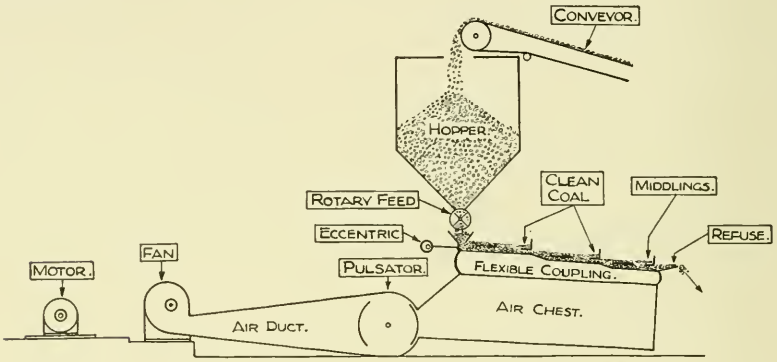

Fig. 2.—Diagrammatic Section of the Static Dry Washer.

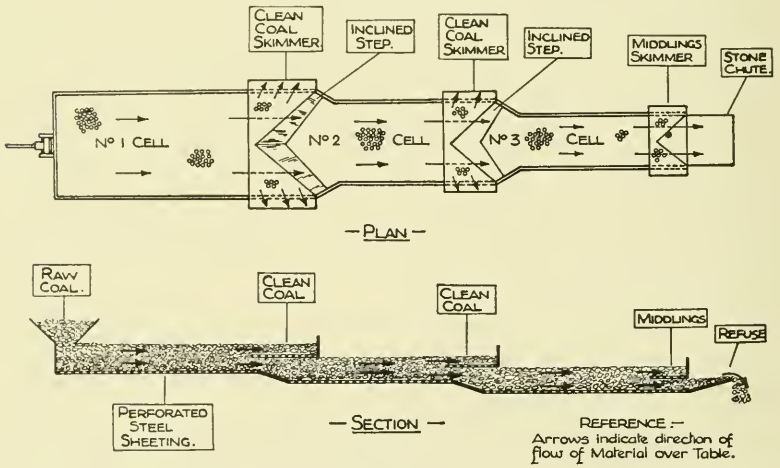

Fig. 3.—Diagrammatic Plan and Section of the Static Dry Washer Table.

It will be seen from Figs. 2 and 3 that the separator deck is of trough form and capable of carrying a bed of coal of considerable thickness. The deck is successively constricted at two points in its length and is thus divided into three rectangular cells each narrower in width than the preceding one. Part of the material is discharged at the forward end of each cell, and the reduced width of the following one allows the remainder to be maintained at the correct depth with respect to the air pressure. The floors of the cells are formed of perforated steel sheeting, the porosity of which is of no particular consequence to the pneumatic operation as the velocity of the air is so low. Small holes have the advantage that less of the fine material falls into the air chest, although the amount of this is never of serious consequence and can readily be withdrawn. The deck surface is quite plain, there being no riffles, guides, or air controlling devices. Reference to the sectional drawing shows that the floors of the three cells are not quite on the same level but are in slightly different parallel planes, the first being elevated above the second and the latter above the last and forward one. The floor of each cell is connected to that of the next by a short downwardly-sloping step which need not be pervious and which in plan is V-shaped.

Immediately to the rear of and above these steps are placed skimmers. These consist of a pair of walls, V-shaped in plan, pointing towards the feed end of the table and carried out over the sides. These walls are mounted on a flat piece of perforated metal sheeting, the rear edge of which is perpendicular to the longitudinal axis of the table and the forward edge is shaped to fit the upright walls. These skimmers separate the strata. They are usually set 3 to 4 in. above the deck surface. At the extreme forward end of the table is a short shoot which is connected to the table by a hinge and provided with screw gear to enable it to be adjusted to any inclination. The refuse or denser material is discharged over this shoot, the quantity being determined by its inclination. The whole deck is built on to a steel girder chassis which is suspended from the over-structure by spring steel hangers.

The table is set so that its longitudinal axis is at a slight downward inclination to the horizontal, to allow of the forward flow of the material.

Beneath the table is a large stationary air chest of rectangular shape, the connection being formed by strong air-tight flexible material. The requisite air pressure is maintained by a fan which delivers air through a large pulsator, thus setting up sharp

fluctuations of pressure in the chest. The pulsator consists of a shaft carrying a pair of discs between which are mounted two oppositely-disposed circumferential vanes. As the discs revolve the vanes pass a port in the air chamber, thus causing a fluctuating pressure to be set up in the air chamber.

The table is oscillated by an eccentric at 300 to 400 rev./min. with $\frac{1}{2}$-in. travel. This is not a propulsive motion, that is, it does not cause a progression of the material. It is purely oscillatory and keeps the bed of even thickness and resistance, and, in conjunction with the slight slope of the deck, allows the distended bed to flow forward, as a liquid flows by gravity, to the points of discharge.

(*b*) *Mode of operation.* In operation coal is fed across the whole width of the rear end of the table by a mechanical feed located in the mouth of a main storage hopper, which is made sufficiently large to ensure regular working of the table. As the coal to be treated is usually the undersize from a $1\frac{1}{2}$ or 2 in. screen leading to the picking belts, a hopper of 20 to 30 tons capacity is usually adequate to take up fluctuations in the flow of coal from the mine.

The mechanical feeder is of the rotary star type, which has been found the most reliable for ensuring a positive rate of feed, and is driven through a variable speed gear to allow the quantity fed to be controlled. A suitable safety device is included in the drive to prevent damage being caused by any large unbreakable object included in the coal. (A copper shear bolt has been found very satisfactory and is replaceable in a few minutes should a stoppage occur.) The coal builds up on the table in a bed, usually 5 to 6 in. thick, according to the setting of the skimmers.

As the bed flows forwards by gravity, the stone and denser materials sink through the coal. Stratification thus gradually ensues in the manner described. By the end of the first cell the upper layers of coal are free of impurities and a direct separation in a vertical plane is made by the intrusion of the flat perforated base of the skimmer set at a suitable height above the deck floor.

It is essential that this operation should be performed without any disturbance of the bed, which must still be maintained in the distended fluid condition necessary to the stratification. For this purpose the strata are divided in knife-edge fashion by the horizontal perforated base of the skimmer. The coal on the skimmer and that below behave exactly as the rest of the bed of coal on the table, and the former in flowing forward is guided to the sides of the

table by the V-shaped upright walls of the skimmer and is discharged as clean coal.

The lower stratum containing the refuse, middlings and some remaining coal flows beneath the skimmer down the inclined step into the next cell, which is of such width that it accommodates this material at the same depth as that in the preceding cell. This material is further stratified and the remainder of the clean coal is similarly removed by the skimmer at the forward end of the No. 2 cell.

The refuse, middlings and coal still remaining flow down another step into the last and narrowest cell, where the final separation is made. The middlings are removed by the last skimmer and are returned by a conveyor or elevator to the feed hopper for retreatment, whilst the refuse is discharged over the stone shoot, the inclination of which is regulated according to the amount to be removed. This final separation is in full view of the operator and can be immediately adjusted to suit varying amounts of dirt in the raw coal.

The circulation of the middlings fraction prevents the clean coal and shale from contaminating each other, thus avoiding the loss of saleable coal in the refuse.

No dust is extracted from the raw coal before being fed to the separator. The statical operation of the pressure (with only a very small passage of air through the bed) allows of the retention of the dust in the clean coal. Some dust is raised a few feet above the deck and all but the most impalpable falls back on to the table and into the shoots. By suitably enclosing the space above the separators, this dust can be prevented from escaping and may, if desired, be passed into the clean coal. A certain quantity of very fine dust must, however, be carried away by the air, but this is of the fine floury character which presents so much difficulty to most commercial systems of dust collection. The provision of such a system does not, therefore, seem warrantable, although, of course, any of them could be applied to the process. It must be remembered that the whole of the dust in the original coal passes over the table and not merely that which is made by attrition and breakage after the bulk has been removed by aspiration which is the case in many plants both wet and dry. The ability to operate at all without an elaborate means of dust collection is, therefore, the more remarkable.

(*c*) *Practical features of Plant.* The salient feature from the economic standpoint of a plant designed to operate on the principles described is its ability to treat the raw coal from the mine below

about 2 to 2½ in. in size without any preliminary sizing or other treatment. This considerably simplifies the process and substantially reduces the capital and operating costs. The introduction of a sizing plant complicates coal cleaning, particularly when the treated coal is to be marketed unsized or in other sizes than those necessary for the separators. Sizing where necessary can more satisfactorily be performed after than before cleaning.

The regular working results show that there is an almost total absence of attrition of the coal during cleaning, this being presumably due to the absence of sizing and to the cushioning effect of the small coal on the larger pieces during treatment.

Fig. 4.—Static Dry Washer Plant, Easington Colliery Co., Durham.

The separators are of simple character from the nature of the process. As the process is concerned almost entirely with stratification, the subsequent separation of strata being a simple operation, the machines are easily controllable and not subject to frequent adjustment. In practice two men are required to operate a plant of 100 tons per hour capacity. The separators offer no difficulty in treating the coal from different seams as it is produced from the mine. No adjustment other than the rate of feed and the rate of stone discharge is usually required.

The compactness and simplicity of the plant permits of its economic use for large or small outputs. It can be operated in single units of

25 tons or upwards per hour capacity, or as large central plants.

(*d*) *Plants in operation.* Static Dry Washers are at present in commercial operation at several collieries in the North of England, with a total cleaning capacity of 280 tons per hour, and other plants are under construction in different parts of the country.

The photographs in Figs. 4 and 5 show outside views of the plants in operation at Easington and South Hetton Collieries.

Figs. 6 and 7 are inside views of the motor house and of the tables respectively on the plant at South Hetton Colliery.

The South Hetton plant consists of two separators, each of 30 tons per hour capacity, and the Easington plant of three separators, each of 50 tons per hour capacity.

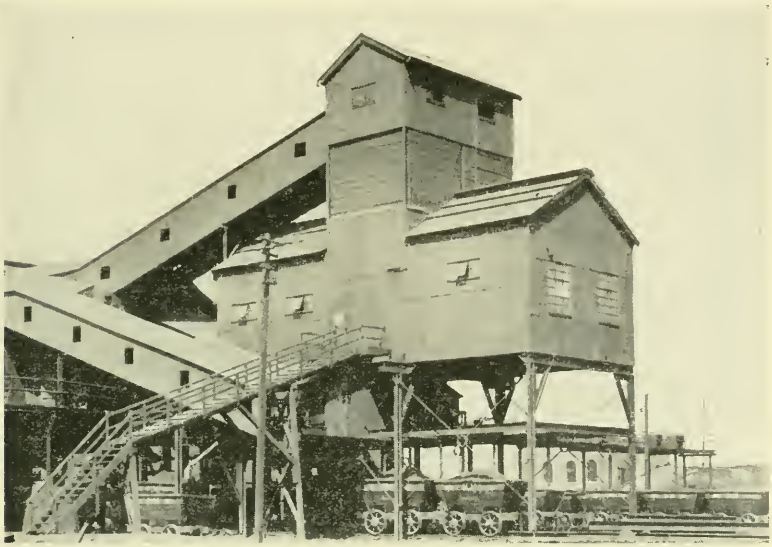

Fig. 5.—Static Dry Washer Plant, South Hetton Colliery, Co. Durham.

Figs. 8 and 9 show in plan and sectional elevation the general standard arrangements for a plant of 100 tons per hour capacity, consisting of two tables each of 50 tons per hour capacity.

(*e*) *Cleaning Results.* Typical average working results taken over lengthy periods from plants at work are the following:—

	Raw Coal.		Clean Coal.	Refuse.
	Ash per cent.	Ash per cent. in Floatings at 1·5 S.G.	Ash per cent.	Ash per cent.
Plant A ...	11·2	4·2	6·3	71·3
Plant B ...	12·8	4·5	7·6	64·6
Plant C ...	11·9	3·8	6·8	69·7

The free coal in the refuse varies usually from $\frac{1}{2}$ to $1\frac{1}{2}$ per cent., representing an average loss of one ton of coal per 1,000 tons treated.

These figures are the overall results, including dust and fine, small coal in the sizes treated, namely, $1\frac{1}{2}$ in. to 0, and represent the daily performances of these plants.

When the cleaned small coal is re-mixed with the large hand-cleaned coal, as is usually the case at the particular collieries in question, these results allow of the cargoes being shipped with overall ash contents of from 5 to $7\frac{1}{2}$ per cent.

In each of the above cases the fines below $\frac{1}{16}$ in. in size are the dirtiest fraction, and when this is pronounced by reason of both a high ash content of these finest sizes and their high proportion in the coal treated, the results may be adversely affected.

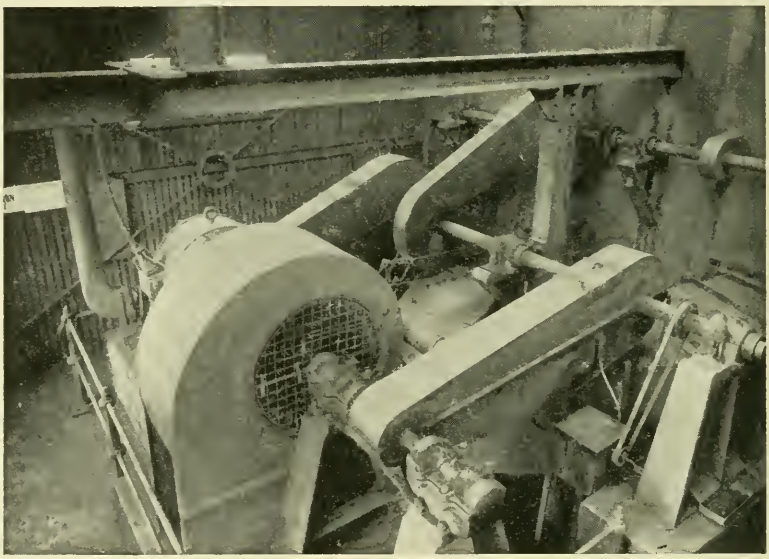

Fig. 6.—Inside view of Motor House on the Plant at South Hetton Colliery.

Many figures and tables might be given of experiments and test results on coals from different parts of the country, but, as in the authors' opinion only practical working results are of any consequence in a discussion of this sort, it is not proposed to prolong the paper by their examination.

(*f*) *Operating Data.* The power consumption on the South Hetton plant is ·85 B.O.T. unit per ton of raw coal treated. This power consumption provides for the conveying of coal from and to the colliery screening plant.

The overall costs at South Hetton over an average week, the plant having a capacity of 60 tons per hour, and treating an average of about 4,500 tons per week, are the following:—

	Pence per ton of raw coal.
Interest on capital at 5 per cent.	·371
Depreciation at 15 per cent.	1·110
Maintenance	·413
Attendants	·838
Electric power	·510
	3·242

The first of these plants was commenced in June, 1927, and has been in continuous operation since that date, other plants having been commenced subsequently.

Fig. 7.—Photograph of the Tables on the Plant at South Hetton Colliery.

The initial cost of a plant of 100 tons per hour capacity approximates to a figure of £10,000 for an average arrangement such as shown in Figs. 8 and 9 inclusive of structure, conveyors to and from the plant, and accessories.

Conclusion

We have to express our appreciation of the mathematical assistance rendered by Professor G. R. Goldsbrough and for the Appendix he has attached to this paper embodying the result of his research.

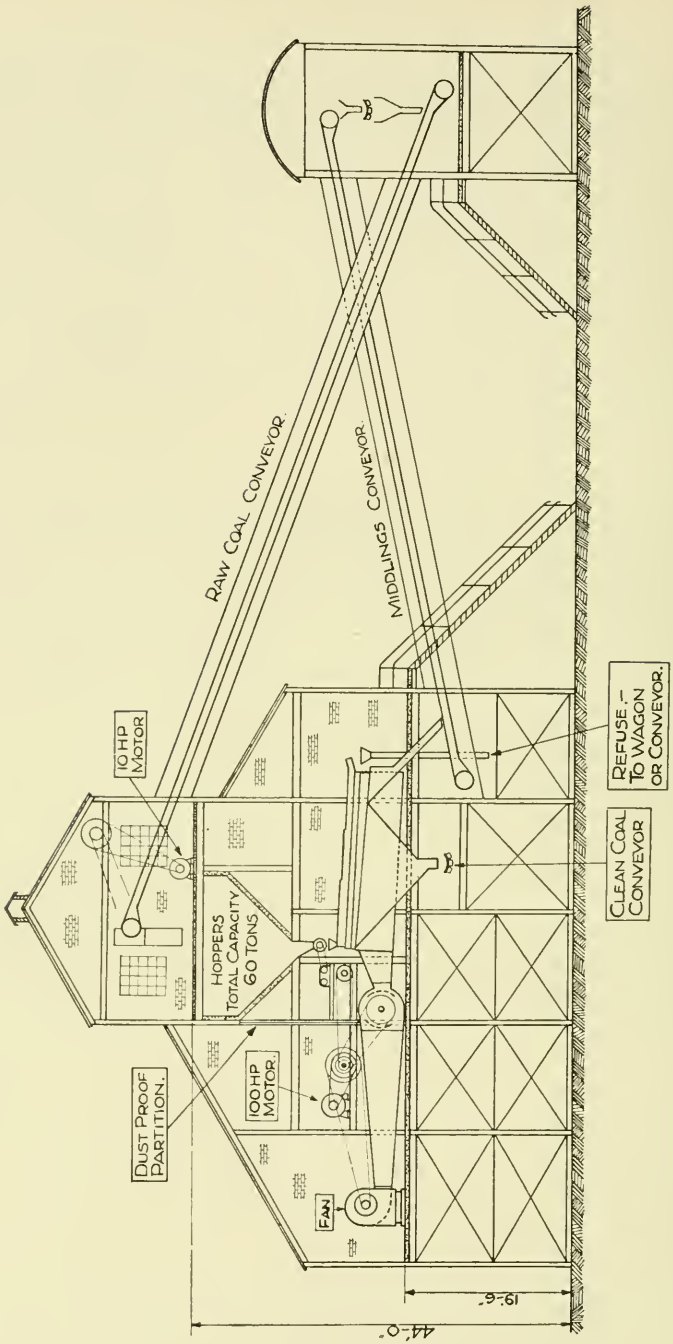

Fig. 8.—Sectional Elevation of General Standard Arrangement for a Static Dry Washer Plant of 100 tons per hour capacity.

We have also to express our indebtedness to the following gentlemen for the experimental services they have rendered:—

Mr. Walter Rider, B.Sc., of Messrs. Dry Washers (Coal & Minerals) Ltd.,

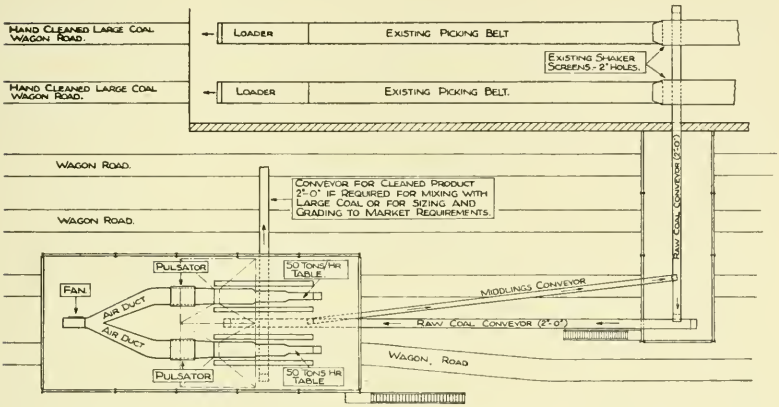

Fig. 9.—Plan of General Standard Arrangement for Static Dry Washer Plant of 100 tons per hour capacity.

Mr. John F. C. Friend, B.Sc., of Messrs. Simon-Carves Ltd.,

Mr. Edward Raffle, of The South Hetton Coal Co. Ltd.,

Messrs. M. Coulson & Co. Ltd., Structural Engineers, of Spennymoor, Co. Durham,

and to Messrs. Dry Washers (Coal & Minerals) Ltd., for supplying the practical operating data given.

APPENDIX

The Mechanical Principles of Separation of Materials of different densities by the use of air

Prof. G. R. Goldsbrough

There are two outstanding methods of using air for separating a mixture of solids of different densities. The first is that in general use in dry coal-cleaning apparatus, which will be referred to as the "terminal velocity" method. The second is described in the foregoing paper, and will be named the "static" method.

1. *The Terminal Velocity Method.* In this method a current of air of sufficient velocity is forced vertically upwards through the bed, and the materials of less density are raised whilst those of greater density settle below them. Thus the materials are arranged in two strata by the action of the air.

It is to be noted that the original bed of materials, being sized, is freely open to the passage of air. The action may then be studied by reference to the effect of a current of air upon a free particle of material.

The materials used ordinarily are of irregular form, but are sized between certain limits. We may study the effects by considering that the statistical results will conform very closely to those of spheres of the same mean diameter. This assumption is the more important in that there are very complete experimental conclusions in regard to spheres but little information on other forms.

As explained in the body of the paper, a body falling under gravity in air is retarded by the resistance of the air, and with increasing velocity there is increasing resistance from the air, until the air resistance just equals the weight of the body. Thereafter, the motion is one of uniform velocity, known as the "terminal velocity," which clearly depends upon the weight, size, and shape of the body. Conversely, a current of air driven vertically upwards against the body, with a velocity slightly higher than the terminal velocity, causes the body to rise, but a current of slightly lower velocity would be unable to support it.

Lunnon[1] has determined the terminal velocities of spheres of various sizes and substances dropped down pit shafts. (His sizes range from 4 to $\frac{1}{8}$ in. diameter.) The results for spheres may be expressed in the form:—

Terminal velocity in cm. per sec. $= 1737\sqrt{d\rho}$, d being the diameter of the sphere in cm. and ρ its density.

If two equal spheres, one of coal ($\rho = 1{\cdot}3$) and the other of stone ($\rho = 2{\cdot}5$) are subjected to the same upward current of air which is adjusted so that it just raises the coal, it is clear that the stone will be unaffected and the result will be a separation of the two. But it is also clear (as is described in most text books on the subject) that the sizing of the material must be between certain limits or clear separation will not result.

This theory and Lunnon's formula appear to represent the process with greater accuracy than has hitherto been supposed. The following working data from a paper by Appleyard [4] which has reference to an S.J. table operating on the above principles may be quoted. The figures are as follows:—

TABLE I.

Table No.	Size of coal, in.	Cu. ft. of air supply per minute.	Pressure of air supply, in., W.G.
1	2—1	17,000	5·5
2	1—$\frac{1}{2}$	12,000	5·0
5	$\frac{1}{2}$—$\frac{1}{4}$	8,500	5·0
6	$\frac{1}{4}$—$\frac{1}{8}$	6,300	3·5
3	$\frac{1}{8}$—$\frac{1}{16}$	5,000	3·0

The area of the deck of this table is given as 17·75 sq. ft. In order to find the actual velocity of the air through the bed, it is necessary to take account of the fact that only the interstices between the separate particles are available for passage of air. An estimate of the percentage of the deck area which allows passage of air may be obtained by considering a surface covered with spheres in close packing.

Let the spheres fit as shown in Fig. 10. Suppose that they are each 2 in. in diameter. If there are n spheres in the first row, there will be $(n - 1)$ in the second, n in the third and so on.

The distance between centres of pairs of spheres in a horizontal direction will be 2 in. In the vertical direction the distance between pairs of lines of centres will be $\sqrt{3}$ in.

Suppose further that there are m rows each containing n spheres, and $(m-1)$ rows each containing $(n-1)$ spheres. There will then be $(2m-1)$ rows

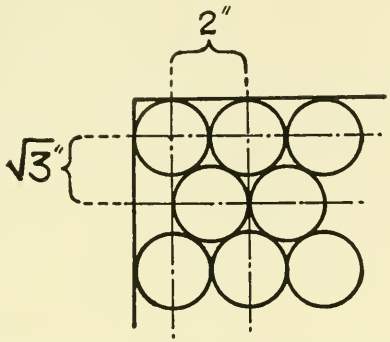

Fig. 10. Diagram illustrating calculation of percentage of area of a layer of equal sized spheres which is open to air flow.

altogether. The length of the table will be $2n$ in. and the depth of the table will be $2+(2m-2)\sqrt{3}$ in. The area of the table $= 2n\{2+(2m-2)\sqrt{3}\}$ sq. in. The areas of the circles representing the spheres

$$= \{mn+(m-1)(n-1)\}\pi \text{ sq. in.}$$

$$\text{Whence, } \frac{\text{Area of circles}}{\text{Area of tables}} = \frac{\{mn+(m-1)(n-1)\}\pi}{2n\{2+(2n-2)\sqrt{3}\}}$$

$$= \frac{(2mn+1-m-n)\pi}{4n+2n(2m-2)\sqrt{3}}$$

$$= \frac{\left(2+\frac{1}{mm}-\frac{1}{n}-\frac{1}{m}\right)\pi}{\frac{4}{m}+4\sqrt{3}-4n\sqrt{3}}$$

Now make m and n large so as to have the effect of a large table covered as indicated.

$$\text{Then, } \frac{\text{area occupied by circles}}{\text{area of table}} = \frac{2\pi}{4\sqrt{3}} = \cdot 907$$

The free space is therefore ·093 of the area of the table or 9·3 per cent.

It is to be noticed that this result is independent of the size of the spheres taken, but implies that the table must be large relative to their size. On a table of the dimensions given this percentage might be slightly larger.

Referring again to the previously quoted S.J. table of area 17·75 sq. ft., it is evident that the effective space for egress of air is 9·3 per cent. of 17·75 sq. ft., or 1·65 sq. ft.

Using this figure with the quoted air supply we can find the actual speeds of the air through the bed. The results are:—

TABLE II.

Table No.	Cu. ft. of air supply per minute.	Speed of air through the bed, ft. per minute.
1	17,000	10,300
2	12,000	7,260
5	8,500	5,150
6	6,300	3,820
3	5,000	3,030

We can further calculate from Lunnon's formulae the requisite terminal velocity to support each size of coal particle quoted in Appleyard's paper. The results are as follow:—

TABLE III.

Table No.	Max. size of coal particle, in.	Terminal velocity requisite, ft. per min.
1	2	9,000
2	1	6,400
5	$\frac{1}{2}$	4,500
6	$\frac{1}{4}$	3,200
3	$\frac{1}{8}$	2,300

These terminal velocities agree remarkably well with those anticipated in Table II.

The discussion can, however, be carried further. The head of water gauge requisite to produce the above terminal velocities can be calculated from the formula, $v = \sqrt{2gh}$. We then find

TABLE IV.

Max. size of coal particles, in.	Terminal velocity per min.	Equivalent head of water gauge, in.
2	9,000	5·4
1	6,400	2·7
$\frac{1}{2}$	4,500	1·35
$\frac{1}{4}$	3,200	0·67
$\frac{1}{8}$	2,300	0·34

The head of water gauge used on the S.J. table for 2 in. particles, is given in Table I. as 5·5 in. The calculated figure is 5·4 in., showing remarkable agreement. The other sizes do not show heads of water gauge the same as those predicted. But the reason is obvious. In the case of the finer particles the actual orifices are much narrower and the frictional resistance to air passage will be much greater. In other words, much of the pressure supplied will be used in overcoming the friction due to the narrowness of the separate apertures, and therefore the actual head of water gauge and the useful head will be very different.

The figure 5·4 in. found for 2 in. particles agrees closely with the 5·5 in. of practice and may be taken to indicate that the calculated terminal velocity 9,000 ft. per min. is in agreement with practice. The supply of air for that size of particle from Table I. is 17,000 cu. ft. per min. Hence the effective free area of the deck must be 17,000 ÷ 9,000 or 1·9 sq. ft. The area previously obtained from the consideration of spheres was 1·65 sq. ft. These two figures agree remarkably well considering the diversity of the methods by which they are obtained.

If, now, we take the effective area of egress as 1·9 sq. ft., and again use the air supply quoted in Table I., we find

TABLE V.

Max. size of particle, in.		Air supply, cu. ft. per min.		Speed of air through bed, ft. per min.
1	...	12,000	...	6,320
½	...	8,500	...	4,470
¼	...	6,300	...	3,320
⅛	...	5,000	...	2,630

These velocities agree even more remarkably with those obtained in Table III. from Lunnon's formula.

For the sake of comparison the calculated velocity necessary to support a coal particle may be compared with those obtained as shown from the working data of the S.J. table.

TABLE VI.

Max. size of particle. in.	Terminal velocity, by Lunnon's formula, ft. per min.	Velocity of air used on S.J. table deduced from assumption of spheres (see Table III.)	Velocity of air used on S.J. table deduced from agreement of pressure (see Table V.)
2	9,000	10,300	—
1	6,400	7,260	6,320
½	4,500	5,150	4,470
¼	3,200	3,820	3,320
⅛	2,300	3,030	2,630

The very close agreement of the calculated velocity of the air necessary to support each size of coal, as shown in column 2, with that obtained from the

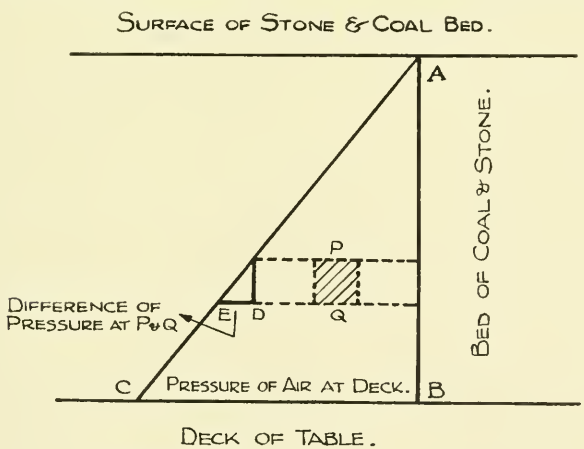

Fig. 11. Diagram illustrating analysis of Static Process.

published working data of one of these tables shows not only that the above theory is correct qualitatively, but that the tables work with very close numerical accuracy to the theoretical conditions. It seems that Lunnon's formula may be used with confidence in dealing with calculations involving the mechanical principles underlying this process of separation.

The form of Lunnon's formula is very similar to that of the oft-quoted Rittinger formula applied to water as a fluid medium. Its superiority lies in the fact that it is derived from experiments carried out with respect to air, and that the coefficient has been accurately determined under carefully defined conditions.

2. *The Static Process.* This process is described in the main part of this paper and is the basis of the new type of table.

To study the conditions arising and in operating the static process, consider a bed of depth AB, as in Fig. 11. At the deck B, the pressure will be that in the chest. At A it will be atmospheric. In the case of a roughly homogeneous bed the pressure will fall off from B to A.

Experimental tests show that in practice with the usual mixed type of bed the pressure falls off with almost mathematical uniformity. If we lay off BC to represent the head of pressure at the deck, the line CA is the pressure line, that is, at any depth in the bed taken on the line AB a horizontal line to AC will give the pressure at that depth.

Consider a mass of material contained between two levels P and Q. The difference of the pressures above and below this mass is represented by DE. This pressure difference is proportional to the depth PQ and indeed:

$$DE = PQ \times \frac{BC}{AB} = PQ \times \frac{\text{Pressure at deck.}}{\text{Depth of bed.}}$$

Now the critical pressure supplied at the deck is such that it will just support the bed if it is of coal only. Broken coal loosely packed weighs 42 lb. per cu. ft. Water weighs 62·4 lb. per cu. ft. The density of broken coal is therefore $\frac{42}{62{\cdot}4}$, or 0·67; To support the bed will therefore require an air pressure of 0·67 in. of water gauge per in. depth of bed. Hence the difference in pressure at P and Q, which as stated above, is $DE = PQ \times {\cdot}67$.

Consider the equilibrium of the mass of material PQ. Let its base area be S. Its weight is $S \times PQ \times$ density of the material. The difference of the thrusts due to the air pressures above and below is $DE \times S$. Hence there will be equilibrium if:—

$$DE \cdot S = S \times PQ \times \text{density of material.}$$

i.e., if $PQ \times S \times 0{\cdot}67 = S \times PQ \times$ density of material.

i.e., if density of material in $PQ = 0{\cdot}67$.

If the material in PQ is only coal particles there will be equilibrium. If there is stone in it the mean density will be greater than ·67 and equilibrium cannot be maintained. Motion will take place, the stone parts sinking downwards until they rest on the deck, and the rest of the coal settling into the now possible equilibrium state.

The conditions for this process to function correctly may be repeated. The bed must consist of unsized materials so that there may be plenty of small particles to form a packed bed. There must be a minimum passage of air through the bed so that the whole of the air pressure may be used in supporting the material. And the pressure applied beneath the bed must be equal to the weight per unit area of the coal in the bed, which it is intended to separate out. It is obvious that the use of sized materials on the bed would be impossible owing to the opportunity for free passage of the air.

The use of oscillating pressures. As has been indicated in the main part of the paper, the stratification of the coal bed by the static method is much

improved by using a pressure which fluctuates rapidly. The optimum conditions for stratification are found to occur when the oscillations of pressure have the highest possible amplitude. The following account shows how this amplitude may be increased by means of resonance.

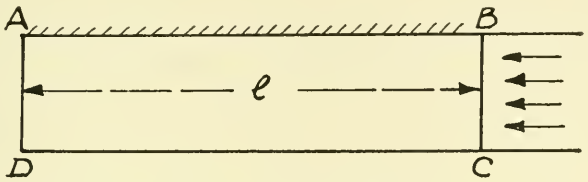

Fig. 12. Diagram illustrating application of Resonance.

A B C D is the air chest beneath the deck A B. At B C the air from the fan is alternately arrested and released by the use of some form of a pulsator. When the pulsator at B C is opened two things happen: (1) a certain quantity of air is admitted, (2) owing to the fact that the pressure outside B C is instantaneously greater than that inside, a pressure wave is generated which immediately travels towards A D.

The amount of air admitted for a given pressure depends upon the leakage through the bed, and in a correctly adjusted plant will be small, and will therefore be neglected. The pressure wave travels with the velocity of sound towards A D. At the face A D it is reflected and returns towards B C, The port B C is now closed and the wave is therefore reflected back again to A D. These reflections would continue, if B C were kept closed, until the wave were damped out and the pressure in the chest again became constant. On the other hand, each time B C is opened, a fresh pressure wave is produced, and the general effect would be a number of waves travelling backwards and forwards indiscriminately. As each wave consists initially of a compression, it must be followed as the port is closed immediately, by a rarefaction. Indiscriminate compressions and rarefactions would in the aggregate tend to annul one another and produce a dead level of mean pressure.

If, however, a wave, once started, arrives at B C after one or more reflections, to find B C just opening, it will be reinforced by the superposition of a new pressure wave. The total amplitude of the two will be greater than that of either. Similarly, if after a definite number of returns to B C the wave always arrives to find B C just opening and there has been no opening of B C in the interval, the waves will be constantly reinforced and will reach a high amplitude.

The magnitude of this amplitude is finally such that the loss of value between each pair of reinforcements, due to frictional forces, is exactly equal to the amount added by each reinforcement.

It is clear then that the pulsator must be tuned to coincide with the return to B C of the wave after one or more reflections at A D. The general effect of this is, apart from the passage of a small quantity of air, to cause the pressure in the chest to oscillate rapidly with large amplitude above and below the mean pressure.

Let l be the length of the chest in feet and V the velocity of sound in air measured in feet per second. The time for a wave to travel from B C to A D and back $= \frac{2\,l}{V}$ sec.

If this journey is made n times, the time to complete the set $= \frac{2\,n\,l}{V}$ sec.

The pulsator must have this time $\frac{2\,n\,l}{V}$ sec. between successive openings.

That is, it must generate $\frac{V}{2\,n\,l}$ pulses per second, or $\frac{30\,V}{n\,l}$ pulses per min.

The quantity n may be 1, 2, 3....., but it is usually necessary to take in a fairly large integer in order that the number of pulses per minute may not be unduly high. Other things being equal, the more pulses per minute that can be given, consistently with the above formula, the more complete is the reinforcement and the greater the amplitude of the pressure wave resulting.

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[2] Martin, Trans. Inst. Chem. Eng., 1926, 4.
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[4] Appleyard, Trans. Inst. Min., Eng., 1927, 73, 404.

ZUSAMMENFASSUNG

Der Bericht befasst sich mit den allgemeinen Prinzipien des pneumatischen Scheidens der Kohle von den Bergen. Ein Anhang gibt eine zahlenmässige Analyse dieser Prinzipien.

An erster Stelle werden die fundamentalen Prinzipien untersucht, die dem Betrieb der unter Anwendung des Widerstandes von Luftströmen arbeitenden pneumatischen Schiedungsmaschinen zu Grunde liegen.

Da keine experimentellen Ergebnisse über die Wirkung des Luftwiderstandes vorliegen, wurden diese Prinzipien empirisch gesucht; sie können zahlenmässig noch nicht genau erfasst werden. Die kürzlichen Untersuchungen und Forschungen von R. G. Lunnon (Proc. Roy. Soc. A., Vol. 110, p. 302, 1926) ergaben Werte für die Wirkung dieses Widerstandes unter ganz bestimmten Vorbedingungen.

Sodann gehen die Verfasser über zur Besprechung eines ganz neuen, von ihnen selbst ausgearbeiteten Verfahrens der pneumatischen Schichtung. Dieses Verfahren beruht auf dem Ausbalancieren des Materialbettes ohne die Einwirkung des auf die Geschwindigkeit der Luft zurückzuführenden Luftwiderstandes. Es wird gezeigt, dass dies erreicht werden kann, wenn man ein aus sehr widerstandsfähigem Material, z.B. aus unsortierter Kohle (2″ – 0) gebildetes Bett einem Luftdruck von bestimmter Grösse unterwirft, der nur von der Gesamtdichte der gebrochenen Kohle und der Dicke des Bettes abhängt. Unter solchen Umständen ist der Luftdruck (der bedeutend geringer ist als der zur Unterstützung der Partikel durch den Einfluss des Widerstandes benötigte, wie beim früheren Verfahren) praktisch ganz damit beschäftigt, den Widerstand des Bettes zu überwinden, was zur Folge hat, dass keine freien Luftströmungen entstehen und dass der Druck in allen

Teilen des Bettes statisch wirkt. In jeder Höhe im Innern des Bettes ist der Druck genau so gross wie das Gewicht der darüberliegenden Kohle, sodass sich das Bett in seiner ganzen Dicke in einem vollständigen statischen Gleichgewichtszustand befindet. Unter diesen Umständen, wenn die innere Reibung im Bett eine solche ist, dass die Partikel sich gegenseitig bewegen können, oder wenn eine Vibration hervorgerufen wird, die die innere Reibung bricht und ein freies gegenseitiges Bewegen der Partikel ermöglicht, dann wird alles Material im Bett, das dichter ist als Kohle, sich nicht im Gleichgewichtszustand befinden, die Kohle verschieben und darunter sinken. Es findet eine Schichtung des Materiales nach der Dichte statt.

Separatoren, die nach diesem Prinzip arbeiten, werden beschrieben. Sie verarbeiten Kohle von etwa $1\frac{1}{2}''$ und $2\frac{1}{2}''$ bis 0 in einer einzigen Operation ohne vorhergehendes Sortieren. Die Anlage ist infolgedessen einfach und im Betrieb leicht auch ohne geschultes Aufsichtspersonal zu kontrollieren. Zum Betrieb einer Anlage von 100 englischen Tonnen Stundenleistung genügen zwei Mann. Das Verfahren kann schon bei einer Stundenleistung von 25 englischen Tonnen zur Anwendung kommen. Das Verarbeiten von Kohlen von verschiedenen Schichten, wie sie vom Bergwerk geliefert werden, bietet keine Schwiergkeiten, bei diesem Verfahren findet auch praktisch kein Brechen statt.

In Nordengland stehen Anlagen mit einer Stundenleistung von 280 englischen Tonnen in Betrieb. Praktische Zahlen, die das Arbeiten dieser Anlagen vor Augen führen, werden wiedergegeben. Die Anschaffungskosten für eine Anlage von 100 englischen Tonnen Stundenleistung betragen etwa £10 000.

THE DRY CLEANING OF COAL

THE INSTITUTION OF MINING ENGINEERS

MAJOR K. C. APPLEYARD

Paper No. C7

CONTENTS

INTRODUCTION—THE NEW "VEE" TYPE SEPARATOR—THE CLEANING OF SIZED AND UNSIZED COAL—THE PNEUMATIC CLEANING PLANT AT THORNE COLLIERY—DUST COLLECTION—MISCELLANEOUS NOTES—BIBLIOGRAPHY—ZUSAMMENFASSUNG

Introduction

Efforts have constantly been made during the last eighty years to develop mechanical apparatus for cleaning coal in a dry condition and with one or two exceptions the pneumatic principle has invariably been adopted. The principal machines evolved have been described recently several times,[1] but almost without exception they failed to establish themselves as commercial successes, and therefore died out.

During the whole of this period the washing of coal by wet processes increased in popularity, particularly in Europe, until at the present time three or four different processes can look back upon many years of continual growth and an established position in the field of coal preparation.

The exceptional advantages of dry clean coal to certain industries has, however, been responsible for a great deal of renewed research into the subject of mechanical processes for dry treatment, and at the present time several forms of apparatus are under investigation in England, these being (1) The Pardee spiral; (2) The Sutton-Steele or Birtley Pneumatic Separator; (3) The Arms Table; (4) The Berrisford Separator; (5) The Lockwood Table; (6) The Kirkup Table; (7) The Raw Table; and (8) The Peale-Davis Table. Some of these machines have also been recently described[2] but only the first two can be said to have reached an established commercial position.

The use of the Spiral Separator is limited to certain specific classes of coal and can have little bearing upon the general fuel problem of Europe as a whole. There are, however, twenty installations at work in England treating approximately two-and-a-half million tons of coal per annum, mainly of the nut or larger sizes. Of the remaining processes mentioned only Nos. 4 and 5 are mechanical, and the remainder pneumatic.

Upon the work of the Americans, Sutton, Steele and Steele, may be said to have been built the whole edifice of pneumatic coal cleaning where it has been commercially applied, and while modern European machines have surpassed the ideas of the originators, to them must be given the credit of departing from earlier ideas and giving the world the basis from which present research on the dry cleaning of coal is largely being carried on.

In the writer's opinion their invention would appear to consist of the application of air to the underside of a bed of coal in such a way as to make the coal buoyant or sufficiently fluid to allow the requisite movement between the particles to enable stratification to take place. This perhaps was not new, but their method of separating the strata by jigging the mass on a specially designed deck was definitely new and their further method of concentrating the heavier particles either against an artificial obstruction or against a sluggish mass of the material itself not only ensured clean products being delivered from the machine, but multiplied its capacity several times and gave an elasticity to the machine that was essential for commercial success.

All the recent developments carried out have been in the direction of improving the method of concentration, but the original principle remains the same as that described above, and which was applied to coal about six years ago.

The essential commercial demand, both in England and in other European countries, is for apparatus to clean small coal, and it is in this field that the pneumatic process is at its best. There are at the present time some eight pneumatic cleaning plants working in England treating nearly 600 tons of small coal per hour, while there are under construction some eight or nine further plants to treat a total of 800 tons per hour. On the Continent of Europe some seven or eight plants are under construction, or projected, in France, Belgium, Germany and Poland, while in America and Canada approximately thirty plants are in operation or under construction for the treatment of small coals below 2 in. It is estimated that by the end of 1928 twelve million tons per annum will be treated by the pneumatic process.

The New "Vee" Type Separator

The most recent type of pneumatic separator that has been installed in England merits a short description. The running mechanism is essentially a development of the Mark IV. running gear, which was designed in conjunction with the Wye Separator. This running gear has been described by Holmes.[3] In the present

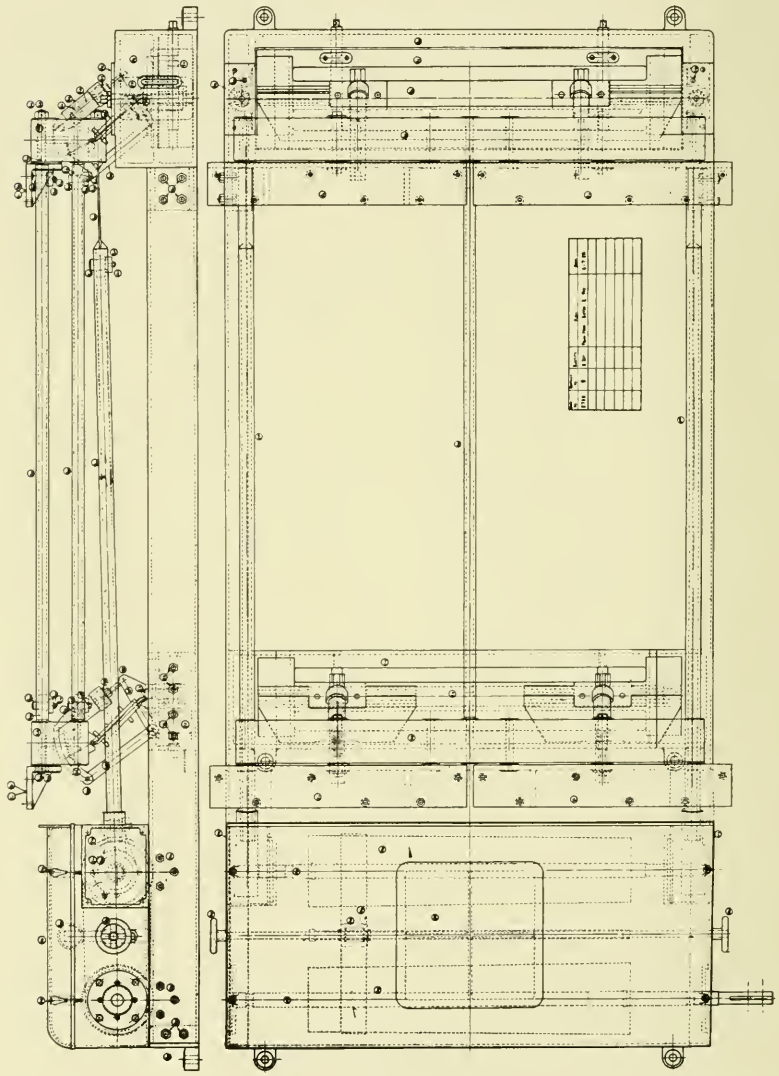

Fig. 1.

instance, however, the running gear illustrated in Fig. 1, is necessarily of heavier construction and incorporates some new features.

The drive to the machine is still taken through a gear box containing two cone pulleys, which are now arranged to incorporate the fly wheels which were originally located outside the gear case. The actual head motion is unaltered and consists of a pair of ball-bearing eccentrics giving a throw of approximately $\frac{3}{8}$ in. connected by eccentric rods to the extreme end of the running gear.

The original arrangement of the toggle plates has been modified and three toggle plates are now used, one at the forward end of the separator and two shorter plates at the rear end. The smoothness of running has been still further increased by altering the arrangement of the springs which hold the machine down to its seating.

By means of an arrangement of links and rocker arms the spring effort is now obtained directly through the centre line of the toggle plates. The lower toggle seatings are, again, adjustable in a horizontal plane, so that the angle of the toggle plates may be adjusted to suit the separation.

The vertical adjustment for altering the facing angle of the deck against the forward travel of the material is now obtained by an adjustment which lifts and locks the lower toggle seating instead of the upper forward beam, and a lower centre of gravity is thereby obtained.

The separating surface (Fig. 2) consists of two decks supported on independent beams so that the spillage angle of each may be adjusted independently. These decks consist of air pervious surfaces having approximately the shape of a V, one side of the V being parallel with the eccentric rods and the other side being curved in towards the apex. The straight side of the V is the spillage edge over which the whole of the products of the separation are discharged, whilst the other side consists of a banking bar which progressively banks up the refuse as it approaches the discharge point at the extreme forward end of the separator. The surface of the deck is equipped with riffles which are inclined away from the spillage edge and towards the banking bar.

In operation the raw coal is fed on to the backs of these decks, the stratification starts immediately, and the heavy particles are deflected by means of the inclined riffles towards the banking bar. Wherever possible the coal is delivered to the separators by means of a gravity feed, but in cases where this is not possible mechanical means have been applied.

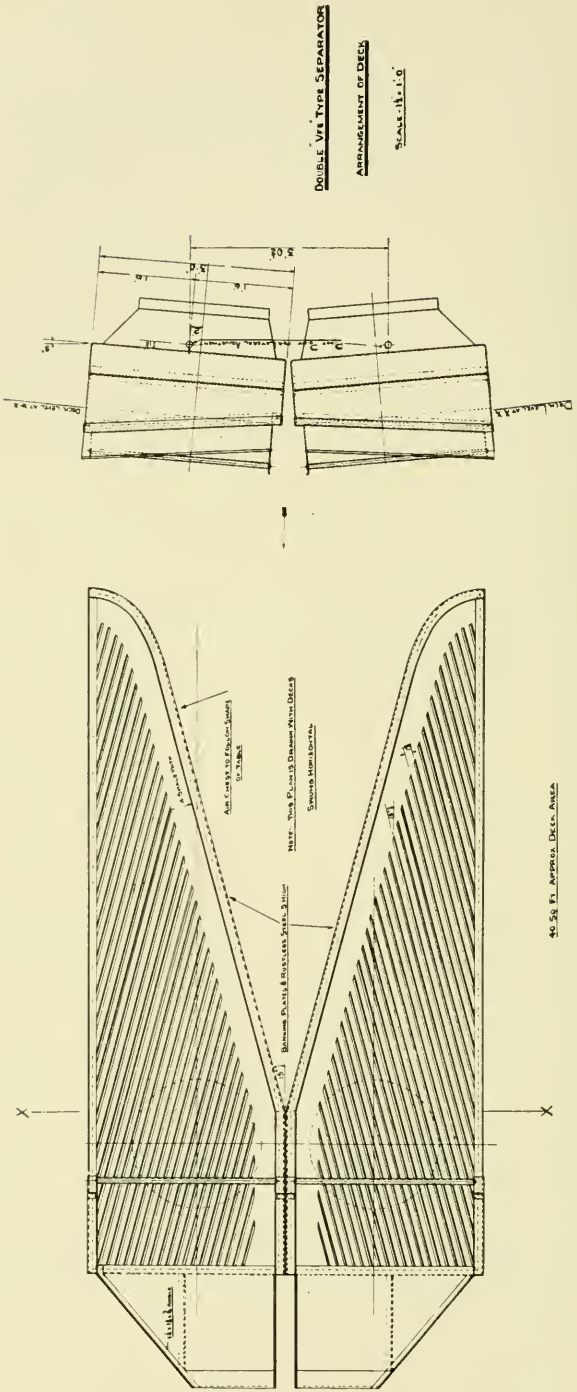

Fig. 2.

The cleaned coal is spilled progressively over an adjustable tailing riffle which runs along the spillage edge of the deck. The progressive spillage of the light particles occurring simultaneously with the concentration of the heavier particles causes an out-crop of refuse at the extreme forward end of the deck, and this piles up against the banking bar, thereby preventing the coal from mixing with the refuse as it discharges from the deck.

By adjustments of the lateral and longitudinal inclination of the deck and the height of the spillage riffle the density and fluidity of the bed can be controlled throughout the machine, with the result that the most favourable conditions are obtained in treating a wide range of sizes at high capacities.

In the treatment of free-cleaning coals separators of this type have capacities up to 100 tons per hour.

The Cleaning of Sized and Unsized Coal

The demands of the coal industry can be broadly separated into two types where the preparation of coal below, say, 2 in. is concerned ; one for a process which will give the cleanest possible coal such as is required for the manufacture of metallurgical coke, and the other a rougher cleaning, having as its object the improvement of the appearance and analysis of the coal to a limited extent.

Up to date all the pneumatic cleaning plants built in England have been in the former class, but their success has brought a pressing demand in the latter class which has resulted in a considerable amount of investigation on the possibility of cleaning coal without preliminary classification.

The extent to which it is possible to do this depends upon two factors. The first is the standard of cleaning required, and the second the type of coal to be treated. If the standard is the normal one, calling for an ash content in the cleaned coal of, say, 2 per cent. above that indicated by the washability curve of the raw coal, and a refuse product containing not more than 2 per cent. of free coal, then it can be said definitely that no dry process treating unsized coal can meet this standard save only in the case of a very few coals which might lend themselves by virtue of their ash distribution to such treatment. On the other hand, if the standard is, say, 4 or 5 per cent. above the fixed ash of the coal with a fairly liberal discard of free coal in the refuse, it is generally possible to meet such a requirement.

When unsized coal is treated by any process, with the possible exception of the Chance process, it is known that there is only a limited range of sizes over which perfect separation can be obtained. Below that range the efficiency of the separation falls off.

Broadly speaking, the problem of cleaning coal either by hydraulic or pneumatic means resolves itself into the problem of separating the largest piece of coal from the smallest piece of refuse. The balance of the separation can be thrown over so as to improve the coal product at the expense of a loss of coal with the refuse, or, alternatively, the refuse can be improved by permitting a larger proportion of the smaller refuse particles to pass away with the cleaned coal.

Coals that lend themselves best to treatment in the unsized condition are those in which the bulk of the free ash is associated with the larger sizes. Such coals, unfortunately, are few and far between, and it is almost universally found that the smaller sizes are progressively dirtier. Tables I. and II. show the compositions of two coals demonstrating these two types of ash distribution.

TABLE I.

Size, in.	Weight per cent.	Ash per cent.	Proportion of total ash in fraction.
Over 1 ...	18·4	11·4	2·10
1 — $\frac{1}{2}$ ...	22·7	16·7	3·82
$\frac{1}{2}$ — $\frac{1}{4}$ ...	20·5	25·5	5·23
$\frac{1}{4}$ — $\frac{1}{8}$ ...	14·1	27·0	3·71
$\frac{1}{8}$ — $\frac{1}{16}$ ...	7·1	32·6	2·32
$\frac{1}{16}$ — $\frac{1}{32}$ ...	6·3	33·6	2·12
$\frac{1}{32}$ — $\frac{1}{64}$ ...	4·3	37·2	1·61
$\frac{1}{64}$ — 0 ...	6·6	40·7	2·70
	100.0		23.61

TABLE II.

Size, in.	Weight per cent.	Ash per cent.	Proportion of total ash in fraction.
1 — $\frac{1}{2}$ ...	10·0	20·6	2·06
$\frac{1}{2}$ — $\frac{1}{4}$ ...	15·6	17·7	2·76
$\frac{1}{4}$ — $\frac{1}{8}$ ...	17·0	12·7	2·16
$\frac{1}{8}$ — $\frac{1}{16}$ ...	18·2	10·0	1·82
$\frac{1}{16}$ — $\frac{1}{32}$ ...	15·4	8·7	1·34
$\frac{1}{32}$ — $\frac{1}{64}$ ...	10·2	9·6	1·00
$\frac{1}{64}$ — 0 ...	13·6	12·6	1·72
	100·0		12·86

TABLE III.

Size, in.	Raw Coal. Weight per cent.	Raw Coal. Ash per cent.	Clean Coal. Weight per cent.	Clean Coal. Ash per cent.
1 — ½ ...	28·0	10·98	23·2	4·28
½ — ¼ ...	34·7	18·76	33·9	4·00
¼ — ⅛ ..	17·7	16·46	21·0	6·16
⅛ — 1/16 ...	8·3	21·30	10·6	14·02
1/16 — 1/32 ...	3·3	25·40	4·2	20·78
Under 1/32 ...	3·5	27·36	2·6	28·54
Dust ...	4·5	18·64	4·5	18·64
Total ...	100·0	18·13	100·0	8·05

Ash content of 1·50 S.G. floatings = 3·35 per cent.
Refuse product contained 1·8 per cent. free coal floating at 1·50.

Table III. shows the results obtained on treating a wide range of sizes on a pneumatic separator and then examining each size separately. The results indicate clearly that although the coal has been substantially improved and that a reasonably pure refuse product has been removed, the cleaning of the coal itself is imperfect—although in this case good enough for market requirements.

Table IV. shows some figures recently published by the American Rheolaveur Corporation which are interesting in comparison, being typical of modern washery practice. They indicate that over a size range of 6 to 1 separation is excellent, but as the range extends to 18 to 1 the separation falls off, and immediately this range is exceeded the separation breaks down altogether, in a similar manner to the pneumatic separation detailed in Table III.

TABLE IV.

Size, in.	Raw Coal. Ash per cent.	Raw Coal. Sink per cent.	Washed Coal. Ash per cent.	Washed Coal. Sink per cent.	Refuse. Ash per cent.	Refuse. Float per cent.
3 7/16 — 2½ ...	18·8	11·0	6·5	0·0	75·5	1·2
2½ — 1 9/16 ...	17·7	12·0	6·5	0·3	84·2	1·4
1 9/16 — 11/16 ...	15·7	10·0	7·6	0·7	80·2	0·5
11/16 — 9/16 ...	14·4	9·0	7·2	1·3	80·6	3·1
9/16 — 5/16 ...	14·4	7·5	10·4	3·2	82·8	2·8
5/16 — 3/16 ...	13·7	7·0	10·1	3·6	81·9	3·4
3/16 — ¾ ...	15·9	10·0	12·9	6·4	61·4	21·5

Many people who are attracted by the somewhat lower capital costs of such an installation fail to realise the heavy financial losses involved by comparatively small losses of recoverable coal in the refuse. Fig. 3 gives some idea of the losses in tons per annum, from which may be judged the financial cost of inefficient coal treatment.

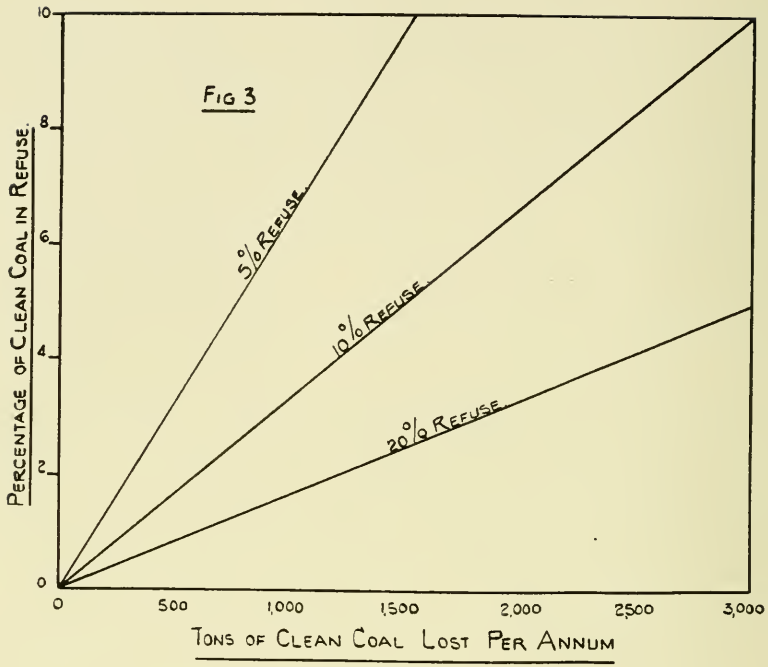

Fig. 3.

Some results of cleaning British and Continental coals are given in Tables V. and VI.

TABLE V.

Size of Coal, in.	Raw Coal. Ash per cent.	Raw Coal. Sink per cent.	Clean Coal. Ash per cent.	Clean Coal. Sink per cent.	Refuse. Ash per cent.	Refuse. Float per cent.	Fixed Ash. (1·50 floatings.) Ash per cent.
1½ — ⅛ ...	15·72	19·7	5·10	3·7	70·4	2·6	4·00
1¼ — 1/16 ...	16·10	20·1	6·58	7·5	76·8	3·4	2·94
1½ — 3/16 ...	9·15	11·4	4·13	3·3	68·3	1·8	3·20
1⅜ — ¼ ...	9·12	9·0	4·96	3·5	80·6	·7	3·63
1⅜ — ⅛ ...	11·43	12·2	6·17	4·6	67·2	1·6	4·06

TABLE VI.

Origin.	Size of Coal, mm.	Raw Coal. Ash. per cent.	Raw Coal. Sink. per cent.	Clean Coal. Ash. per cent.	Clean Coal. Sink. per cent.	Refuse. Ash. per cent.	Refuse. Float. per cent.	Fixed Ash. (1·50 floatings.) Ash. per cent.
Ruhr	10 — 0·5	13·74	15·5	6·35	5·9	73·3	2·8	3·77
	10 — 0·0	(13·76)		(7·41)				
Belgium	10 — 0·5	16·59	21·3	4·90	5·2	71·4	3·5	3·26
	10 — 0·0	(17·34)		(7·65)				
France	20 — 0·5	31·30	38·9	8·84	7·6	81·5	2·7	4·98
	20 — 0·5	(29·45)		(10·05)				

The Pneumatic Cleaning Plant at Thorne Colliery

A description of the pneumatic cleaning plant at the Thorne Colliery of Messrs. Pease & Partners, Ltd., may be interesting in view of the fact that it is probably the most modern plant at work in any country, and also that it is the first plant to be put into operation in which the dust collected during the process of cleaning is drawn away for final pulverisation, and burned under water tube boilers.

The capacity of the installation is 130 tons per hour and the raw coal is taken direct from the underside of the main screens to an overhead 130 ton bunker, from which it serves into an underground 70 ton bunker which can also be filled from railway wagons.

A main elevator of the continuous bucket type delivers the raw coal on to a Hum-mer Bull-dog Tandem vibrating screen which separates the raw feed at $\frac{1}{2}$ in., the oversize product being subsequently re-screened over a Hum-mer Standard 4 ft. vibrating screen, and the undersize being re-screened at $\frac{1}{8}$ in. on a Hum-mer Bull-dog Tandem.

The coal that is treated in this plant at present is from the High Hazel seam, and in common with the bulk of South Yorkshire coal, the ash content of the raw coal rises in the finest sizes.

As has previously been stated, it is desired in this plant to make, and market, a $\frac{1}{2}$ in. coking slack; and this product is of considerable interest, primarily because it has been cleaned without replacing the refuse by moisture, and also because the dust has been removed from it in the cleaning process.

During a preliminary examination of this coal, it was found that in the dust of 100 mesh size the caking index was only 40 per cent. of that in the sizable coal, while the finest dust consisted almost entirely of fusain, and was not only non-coking, but would only coke when mixed with a considerable quantity of larger coal. Thus, by removing the dust, the coking properties of this slack have been considerably improved. Further, this fine dust contained nearly twice as much sodium chloride as the bulk of the coal, and this objectionable material is therefore reduced in the slack which is being marketed.

In spite of the fact that this dust is so objectionable from a coking standpoint, it has nevertheless one virtue, a reasonably high calorific value, and advantage is taken of this property by using it as pulverised fuel in water tube boilers.

It seems highly probable that this practice will, in the near future, find a progressively wide application as the disadvantages of

carbonising such dusts are more widely appreciated, and as the combustion of pulverised fuel becomes more popular.

The separator floor houses four Wye type pneumatic separators, making the following market sizes :—

Doubles	1½ to 1 in.
Singles	1 to ½ in.
Beans	½ to ⅛ in.
Slack	⅛ in. to 0.

The clean coal is delivered by means of shoots fitted with anti-breakage devices on to the floor below, where the conveyors are so arranged that the whole of the cleaned coal can be re-mixed and returned to the colliery screening plant, where it can, if desired, be re-mixed with the larger sizes. Alternatively, the two larger sizes can be loaded separately and the two smaller sizes mixed to give a ½ in. slack.

The middlings are collected on to a common belt running the full length of the building, and are returned to the raw coal feed. The refuse from all machines is fed on to a common belt conveyor running the full length of the building, which, in turn, delivers on to a cross belt conveyor, by means of which the material is loaded up into wagons.

The separator treating the smallest size is equipped with an aspirator to remove the finest dust. This dust is discharged into a cyclone where the bulk of it is collected, and the cyclone discharge is connected to the main bag filter.

All the separators are totally enclosed by steel hoods and these are connected to the common dust extractor fan and the bag filter.

The dust from both the cyclone and the bag filter is collected by a screw conveyor and fed into a dust elevator which discharges into the top of a dust bunker having a capacity of 150 tons. From here it is pneumatically conveyed to the boiler house.

The total installed horse-power is 226, approximately one-third of which is devoted respectively to the elevators and conveyors, separators and separator fans, aspiration and dust collection.

The air consumption is rather more than 20,000 cu. ft. per ton of coal treated.

The plant is illustrated in Figs. 4 and 5.

In conclusion it is of interest to note that the whole operation of the plant is controlled from the separator floor. Here the control panel is linked up to the contactor house on the floor above, and by pressing the main start button the operator sets the contactor in motion, which, in turn, starts up each unit of the plant in its proper sequence.

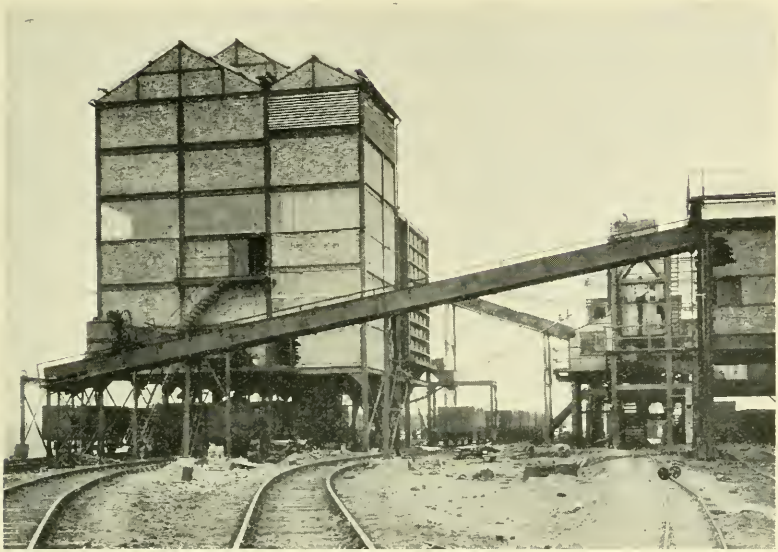

Fig. 4.

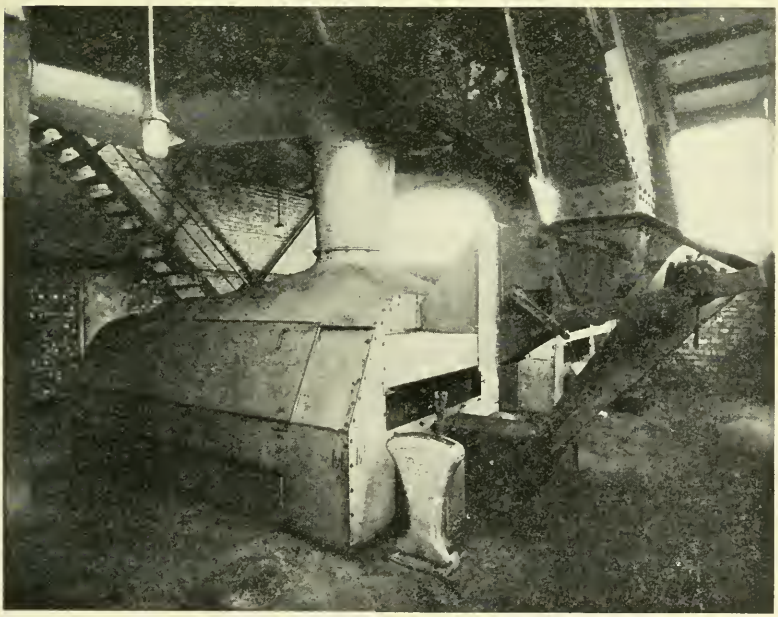

Fig. 5.

By means of this automatic starting arrangement any possibility of the operator running coal on to a stationary conveyor or operating the main elevator with the plant standing is eliminated.

The essentials of pneumatic separation in commercial plants may be said to be:—

(1) Size classification within limits to be determined for individual coals.

(2) A regular feed of approximately the maximum quantity of coal for which the separator is rated.

(3) The removal of fine dust from the smallest size of coal before it is fed to the machine.

Dust Collection

In connection with the latter product I have described elsewhere[4] a number of methods of dust collection, their advantages and their disadvantages, and it cannot be said that the problems of dealing with dust are even approaching final solution.

The finest dust is undesirable in a pneumatic separator treating fine coal, say, below 0·1 in., since it tends to prevent the fluidity of the bed which is essential to stratification. So far as possible, therefore, it is necessary to remove it before feeding the raw material to a machine. This is now done on the normal type of aspirator or de-duster such as is commonly found in washery plants in Germany. Any further dust made by abrasion of the coal particles is removed by suction from the hood, which usually encloses each separator, and it remains for the dust to be removed from the air stream. This is at present done by passing the dust-laden air into a collector which is a combination of a cyclone and a bag filter (see Fig. 6).

The larger particles of dust are deposited by centrifugal force and expansion, and the air carrying the lighter particles rises through the bags and passes out through the filter tubes leaving the finest dust inside. It is possible with this type of filter to obtain a differential separation of dust, and so to regulate in some degree the quantity of finest dust to be drawn off for boiler or other purposes.

The dusts that are collected in filters which operate in conjunction with pneumatic separator plants are of considerable interest, and some figures are given in Table V. showing the relative fineness of dusts from four sources. Nos. 1 and 2 are from Durham gas coals, No. 3 from a Lancashire coking slack, and No. 4 from a Kent coal.

The proximate analyses and calorific values of these four dusts are given in Table VI. These figures are all taken from samples obtained in commercial operation. Unfortunately, comparative

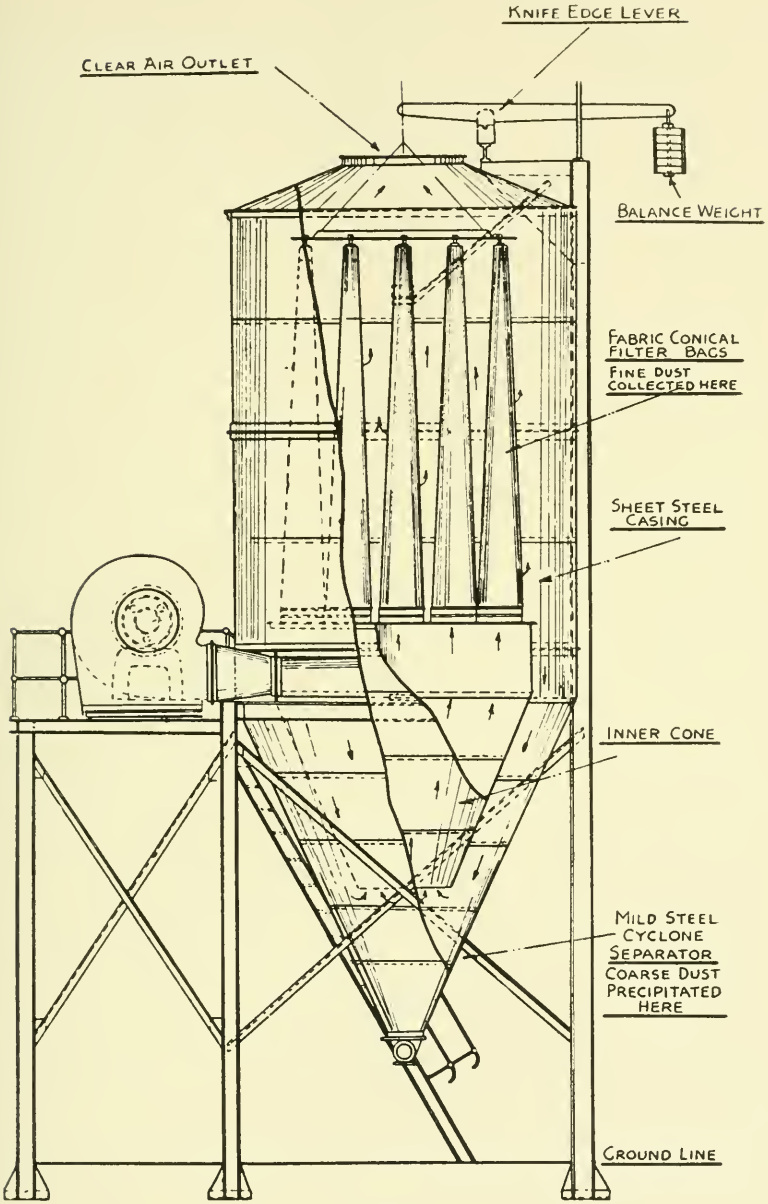

Fig. 6.

figures from the Thorne plant are not yet available, although there is no doubt that in this case the ash content will be higher than in the instances cited in Table VI.

TABLE V.

Size of Screen, Opening. in.	Mesh.	Per cent. of Total Dust.			
·0328	20	5·0	6·0	Nil	1·5
·0232	28	7·5	8·0	Nil	4·5
·0164	35	13·0	11·5	2·0	5·0
·0116	48	20·5	18·5	4·4	27·0
·0082	65	14·0	12·5	12·0	14·5
·0058	100	15·0	16·0	25·2	17·0
·0041	150	9·5	11·5	21·6	10·0
·0029	200	3·5	5·0	24·4	4·0
Pan		12·0	11·0	10·4	16·5
		100·0	100·0	100·0	100·0

TABLE VI.

	1.	2.	3.	4.
Moisture, per cent.	1·90	2·00	1·55	1·00
Ash, per cent.	11·86	12·02	9·18	9·22
Volatile Matter, per cent. ...	29·30	29·72	31·40	21·22
Fixed Carbon, per cent. ...	56·94	56·26	57·87	68·56
Calorific Value, B.Th.U. per lb.	13,760	13,460	—	14,560

It has been found in practice that the dust removed from the filters has an ash content of only approximately four-fifths that of the dust in the raw coal. This fact, which has been amply proved in commercial operation, is borne out by figures obtained by Mr. A. N. Harrison Slade, of Birmingham University, who found over a number of tests that the ash content of the collected dust averaged between 75 and 80 per cent. of that found in the untreated dust, Thus, if the ash content of the dust in the raw coal is 20 per cent., the ash content of collected dust will probably be about 15 per cent. This is due to the fact that the air current drawing off the finest particles tends to reject the largest particles of shale and pyrites, and, in consequence, the larger fraction of the collected dust is often found to have quite a low ash content.

It is usual to find a higher ash content in the dust below $\frac{1}{64}$ in. than in any other fraction of the raw coal. This is not universally true, especially in the case of very friable coals, where the reverse may be the case. This latter tendency is noticed in some Welsh coals, more especially in Continental coals, and in coals from the Kent coalfield. As a matter of purely technical interest, it is generally found that in dusts having high ash contents the very finest portion, say through 200 mesh, which consists almost exclusively of fusain, has a rather lower ash content than the dust of slightly larger size.

Generally speaking, there is only one valuable property associated with coal dust and that is its calorific value, and although a number of cases might be cited where the dust can be usefully remixed with the bulk of the cleaned coal for carbonisation or combustion, there is a great deal to be said for the rapidly growing practice of burning this dust as pulverised fuel. There are at the present time two factors which tend to delay the wider adoption of this practice. The first lies in the difficulty that is encountered in the transporting of dust by rail or road in this country. It is common practice in Germany to transport coal dust by rail at rates that have become quite an attractive proposition from a commercial standpoint. In the United States large quantities of coal dust, usually for pulverising purposes, are transported by means of motor lorries fitted with tank bodies from the pulverising plant to small individual users. Efforts are being made in this country to persuade the railway companies to remove the present restrictions on the transporting of coal dust by rail, and it is hoped that in the near future it will find a ready market for use in central power stations as pulverised fuel.

The second factor that has retarded the development of the use of coal dust as a fuel at the pit head is the fact that a large number of collieries are equipped with Lancashire boilers in which, until very recently, it was impracticable to burn pulverised fuel, and the cost of replacing them by water tube boilers is so high as to render the change unattractive from a commercial standpoint; while many collieries use in their Lancashire boilers, either from choice or of necessity, a feed water so hard as to render the operation of water tube boilers impossible.

It would appear that the problem of burning coal dust satisfactorily in Lancashire boilers is now approaching solution, and in consequence coal dust as a fuel may now make much greater appeal both to the colliery engineer and to the small power user generally.

Such dusts as have been described are not sufficiently fine to permit of complete combustion, and must be still further reduced in size before they can be efficiently burned. They have, however, an advantage in that they are already of reasonably small size compared with fuels that are usually pulverised; but in practice this is not found to be so great an advantage as might appear to be the case at first sight. The fact, however, that they are invariably free from large pieces of abrasive material such as shale or pyrites, and that they cannot possibly contain bolts, nuts or coal-cutter picks which are frequently found in slack coal, and which have disastrous effects on pulverising machinery, constitutes a very real advantage.

One of the greatest hindrances at present to the progress of pulverised fuel practice lies in the heavy cost of upkeep of the pulverisers. It is of interest to note in this connection that the author is at present associated with an extended series of experiments covering the use of several thousand tons of coal, with a view to determining the relative costs of pulverising raw coal and coal that has been freed from shale and pyrites by means of pneumatic separation.

Apart from the use of coal dust as pulverised fuel for steam raising, it should also find considerable application in connection with the manufacture of Portland cement; whilst, although the market is more restricted, a large quantity of coal dust from the dust collectors in pneumatic cleaning plants has been sold for use in iron foundries.

In the United States there are a number of open-hearth steel furnaces and other metallurgical furnaces which are fired exclusively with coal dust; and provided that dusts reasonably low in ash and sulphur are available, there is not the slightest reason why many more furnaces should not be similarly fired.

Miscellaneous Notes

Moisture.—It is not yet possible to lay down definitely any formulae for determining the percentage of moisture which defeats the process of pneumatic separation.

Generally speaking, however, it may be said that provided the coal is not so wet as to prevent sizing at about $\frac{1}{8}$ in., moisture content matters very little. But below $\frac{1}{8}$ in. the margin of surface moisture permissible is not high. Slade[2] states that on the experimental table at Birmingham University, when treating coal $\frac{1}{8}$ in.-0 in size, he reduced the surface moisture from 3·6 to 2·6, or 28 per cent. by passing the coal over the separator once, and on re-mixing and cleaning improved the overall efficiency by 13·5 per cent. After further reducing the moisture content to 0·5 per cent. by several further circulations over the machine, he obtained a further increase in efficiency of 16·5 per cent.

There is no reason to doubt that these figures give an approximately correct idea of the effect of moisture on very fine coal where particle adhesion is greatest and most difficult to break down. Inherent moisture has no effect on the cleaning operation.

Costs of operation.—Figures obtained from the commercial plants at present at work in England indicate that the operating costs of a cleaning plant (clean coal basis) average as follows:—Total operating cost, including inside staff, power, maintenance and

repairs, approximately 2·25d. per ton, power being charged at ·875d. per kWh. The labour cost is 0·35d. per ton and the power consumption 1·85 kWh.

Advantages of Dry Cleaning.—The inherent advantages of clean and dry fuels appeal instantly to those who are accustomed to purchase and utilise them with full knowledge of their subject. Much has recently been written on the subject, and there appears to be an approach to unanimity amongst authors.

In the steam raising, coke and gas manufacture, the advantages and economies are so far-reaching as to prevent their full consideration here, although some discussion of them may be found in previous papers.[1, 2]

It is interesting to note in connection with advanced coke oven practice that two batteries of coke ovens now under construction in England, of different Continental types, are both being provided with dry preparation plant.

Briquetting.—In the manufacture of briquettes, a reasonably low ash content in the finished briquette is essential, and it is usually necessary, therefore, to wash the fine coal from which the briquettes are to be made, and as the raw material of the briquette industry is usually below $\frac{5}{16}$ in., the moisture content of the washed coal is necessarily high, ranging from 12 to 16 per cent.

Before such a product can be sent to the briquetting plant it must be dried, and in order to effect this a considerable quantity of coal has to be burnt, usually amounting to about 15 per cent. of the total weight of coal dried.

Taking into consideration the cost of labour, repairs and depreciation, the substitution of dry for the wet process of preparation should reduce the cost of the coal delivered to the briquetting plant by probably 25 per cent.

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4. Appleyard, Trans. Inst. Min. Eng., Vol. LXXIII., pp. 404–440.

ZUSAMMENFASSUNG

Der Bericht befasst sich kurz mit der Entwicklung des Scheidens der Kohle von den Bergen auf trockenem Wege und den verschiedenen Verfahren, die gegenwärtig entweder schon ausgebeutet werden oder die sich noch im Versuchsstadium befinden. Es wird die Stellung der pneumatischen Scheidung in England betrachtet, wo gegenwärtig 600 englische Tonnen pro Stunde

geschieden werden. Die im Bau befindlichen Anlagen werden diese Leistung auf 800 englische Tonnen pro Stunde erhöhen. In Europa befinden sich mehrere Anlagen im Bau; die in der ganzen Welt behandelte Menge beläuft sich auf ungefähr 12 Millionen englische Tonnen jährlich.

Die Konstruktion des "Vee"-Scheiders wird eingehend behandelt, desgleichen die Verarbeitung von der Grösse nach nicht sortierten Kohlen. Zahlen zeigen, wie die Wirksamkeit sowohl bei trockenem wie bei nassem Scheiden mit der Grösse der Kohlen wechselt. Die moderne Trockenscheidungsanlage der Thorne Colliery in der Nähe von Doncaster in England, die 130 englische Tonnen Kohle von $1\frac{1}{2}$" bis 0 pro Stunde verarbeitet, wird eingehend beschrieben. Diese Anlage umfasst 4 Separatoren vom "Wye"-Typ; sie trockenscheidet Kohle in Nuss- und Schlackengrösse für den Markt. Die Betriebskosten einer pneumatischen Scheidungsanlage werden mit 2,25 Pence pro englische Tonne angegeben.

Weiterhin wird der Staubsammler in Verbindung mit der Trockenscheidung der Kohle behandelt und die Verwendung des gesammelten Staubes als Staubbrennstoff beschrieben. Es wird auch der Einfluss des Feuchtigkeitsgehaltes von Rohkohle auf die Trockenscheidung besprochen. Bei der Behandlung der Vorzüge der Trockenscheidung wird darauf hingewiesen, dass zwei gegenwärtig im Bau befindliche Koksöfenanlagen in England mit pneumatischen Scheidungsanlagen arbeiten werden, was natürlich die Leistung der Öfen bedeutend steigern wird im Vergleich mit nasser Kohle.

Die in der Brikettindustrie dank der Trockenwaschung erzielten Ersparnisse werden gestreift; der Bericht schliesst mit einer Betrachtung der erzielbaren Frachtersparnisse beim Transport trocken geschiedener Brennstoffe.

Dem Bericht sind Lichtbilder einer modernen pneumatischen Scheidungsanlage beigegeben. Tafeln zeigen die Ergebnisse von Kohlescheidungsversuchen, auf die im Text verwiesen wird.

GENERAL REPORT ON SECTION C

COAL TREATMENT
(*a*) CLEANING, (*b*) DRYING, (*c*) BRIQUETTING

DR. W. R. CHAPMAN

1 There are seven papers presented to this section of the Conference, entitled :—

C1 Cleaning Bituminous Coal (U.S.A.), by J. R. Campbell.
C2 The Drying of Brown Coal without Breakage (Austria), by Prof. Dr. H. Fleissner.
C3 The Dewatering and Drying of Coal (Great Britain), by R. A. Mott.
C4 The Cleaning of Small Coal (Great Britain), by Dr. W. R. Chapman.
C5 The Cleaning of Coal by Froth Flotation (Great Britain), by Prof. E. Edser and P. T. Williams.
C6 The Principles of Pneumatic Separation with a description of the Static Dry Washer (Great Britain), by Geo. Raw and F. F. Ridley.
C7 The Dry Cleaning of Coal (Great Britain), by Major K. C. Appleyard.

2 The subject matter dealt with in these papers may be divided under the following headings :—

(*a*) Description of coal-cleaning processes.
(*b*) Principles of pneumatic separation.
(*c*) New types of pneumatic separator.
(*d*) Comparison of coal-cleaning processes.
(*e*) Dewatering and drying bituminous coal.
(*f*) Drying of brown coal.

(*a*) *Description of Coal Cleaning Processes*

3 Coal too small to be hand-picked economically can be cleaned by a number of mechanical processes. Of the coal cleaned in Europe, about 90 per cent. is cleaned in jigs of one type or

another or in Rheolaveur washers, but there are a number of other processes with merits for special purposes which are frequently worthy of consideration as alternatives to the more widely adopted processes.

4 All modern processes are described by Chapman (C4). He outlines the principles used in the following processes:—Jigs (Baum and others), Rheolaveur, Draper, Chance, concentrating tables, froth flotation, pneumatic separators, spiral separators; all of which have been widely adopted; and he describes briefly the following new processes: Raw, Berrisford, Lockwood,[1] Clean Coal Co., Kirkup. The description points to the relative advantages and limitations of different processes.

5 Campbell (C1) also gives some particulars of American practice with the Rheolaveur process, concentrating tables, and the Menzies hydro-separator, and froth flotation is described at some length by Edser and Williams (C5).

6 Particular interest attaches to the description of dry-cleaning processes, especially by Raw and Ridley (C6) and Appleyard (C7), for although dry-cleaning processes are not as efficient as the principal wet-cleaning processes, dry cleaning has an attraction in many cases, which will certainly lead to its wide adoption. For this purpose pneumatic separators are likely to be most widely adopted, but spiral separators and the Berrisford and Lockwood processes are alternatives.

(*b*) *The Principles of Pneumatic Separation*

7 Raw and Ridley describe at length the principles used hitherto in pneumatic separators of the S.J. and Wye types (American Coal Cleaning Corporation and Birtley Iron Co.). Figures are quoted in the appendix to their paper (by Prof. G. R. Goldsbrough) to show that the principle is that known as "terminal velocity" operation. This principle can only be employed efficiently with sized coal.

8 In an attempt to improve upon the efficiency of pneumatic separation with unsized coal, Raw and Ridley conducted experiments that have led to the design of a new process—the Static Dry

[1] The process formerly known as the Dry Coal Cleaning Co.'s process is now called the Lockwood process.

Washer. In this process air is used in a manner differing from that of its use in earlier appliances.

9 Instead of being supplied as a current of air of sufficient velocity to support the coal particles dynamically, the bed is made to act as a piston. Being unsized, the coal can pack closely together, and if air is supplied at a critical pressure it can be made to support the bed statically and bodily, much as an air pressure can support a piston. The pressure applied is equivalent to the depth of bed multiplied by the "bulk-density" of coal (0.67), and, in the fluid condition induced, the heavy dirt can work its way to the bottom of the bed and displace the coal into the upper layers. The critical pressure applied to the bed is less than that required to set up terminal velocity conditions.

(c) *New Types of Pneumatic Separators*

10 Appleyard (C7) describes a new pneumatic separator—the "Vee" type—introduced as an improvement on the well-known "Wye" type. The "Vee" separator is of similar general construction to the Wye, but the deck-shape has been altered, the outer (spillage) edges being straight and the arms of the Y being considerably extended. The separating surface consists of two decks supported on the same framework. The method of separation is essentially the same as in earlier types and the improvements are largely constructional, emphasising certain features of the former design to obtain better results.

11 The Static Dry Washer, described by Raw and Ridley, is also a new process operating according to the principle already stated. The apparatus consists of a jigging trough divided longitudinally into cells. The coal stratifies in the first cell and the uppermost layers are removed by skimmers. It is essential to maintain a uniform thickness of coal bed along the whole length of the trough, and to allow for the coal removed by the first skimmer, the trough is narrowed sharply as the coal passes down an inclined step from the first to the second cell. Here the stratification is completed and more coal is removed. The middlings and dirt are separated in a third cell, also connected to the previous cell by an inclined step and a constriction.

12 It has been found advantageous to use an oscillating pressure, obtained by supplying air through a pulsator to an air-chest below

the trough. The air-chest is so shaped and the pulsator so timed that resonance is set up in the chest, each accession of pressure being timed to coincide with the return of a reflected pressure wave.

13 Appleyard, discussing the cleaning of sized and unsized coal, states that unsized coal can only be cleaned on pneumatic separators if the standard of cleaning is low, *e.g.*, that the ash content of the coal is reduced to within 4 or 5 per cent. of the fixed ash and a fairly liberal discard of free coal with the refuse is allowed. The results for the Static Dry Washer fall well within these limits, however.

14 It has usually been thought, hitherto, that the first pneumatic separator used for coal cleaning was the C.J. table (Sutton, Steele and Steele patent), but Campbell (C1) records from personal experience that the Bonson table was used in 1914.

15 The collection and disposal of the dust have always been difficulties in the way of pneumatic separation, and it is interesting to see that the dust from the dry-cleaning plant at Thorne Colliery is drawn away and burned under water tube boilers at the colliery—the rational method of disposal. The usual method of collecting dust now adopted is to pass the dust-laden air into a combined cyclone and bag-filter (C7, Fig. 6). The larger dust particles are deposited as the air expands in the cyclone and the finer particles are trapped by the bags through which the air escapes.

16 The dust collected is stated to have a lower ash content than that in the original coal, owing to a differential separation by the air current.

(*d*) *Comparison of Coal-Cleaning Processes*

17 When an operator has to choose what type of process to install he is too frequently compelled to make first cost the only consideration. This is unfortunate, and where it does not obtain, information relative to the comparison of processes is valuable. The relative merits of many processes may be judged from the papers contributed, and the following factors have been put forward as the most worthy to be taken into consideration in choosing a process :—

The market for the coal.

The effect on the total cost of production of the marketable product.

The circumstances in which the process must be operated.

The last factor includes the nature of the existing plant; the space available; the degree of cleaning and sizing required; the nature of the raw coal; the regularity of the seams; the throughput required; water supply and requirements.

18 Various figures are given for the cost of operation of different processes, *e.g.*, by Appleyard, Raw and Ridley, and Campbell. It is doubtful if these figures are comparable, and it would be valuable to be able to make them so. To be comparable the figures should be for a plant of a certain size (*e.g.*, 100 tons per hour); power and wages rate must be reduced to a uniform basis; rent, management expenses, capital charges must also be on a standard scale; and any royalty payable should be stated. It would be interesting to have further information on these points in the discussion in order that a true comparison could be made.

19 Campbell (C1) draws attention to the charge for loss of output as refuse, and the loss of coal in the refuse. The total loss of this kind—bank loss—may assume considerable proportions. Appleyard (C6) also deals with this loss and gives a graph (Fig. 3) showing the amount of coal lost annually in the refuse under different conditions. To interpret this graph the size of plant for which it is calculated should be given.

20 Chapman (C4) discusses the total cost generally and shows, in particular, that the loss of output per 1 per cent. of ash reduction increases greatly the lower the ash content required. Thus the ash content may be reduced from 8 to 6 per cent. by rejecting 2.6 per cent. of material, but to reduce the ash content from 4 to 2 per cent., the minmum amount of material that can be rejected is 12.5 per cent. of the total. This is a factor that must be borne in mind by consumers who demand very clean coal, and they must be prepared to pay substantially for the advantages they obtain.

(*e*) *Dewatering and Drying Bituminous Coal*

21 The various types of appliance that may be used to dewater and dry coal are:—Drainage hoppers and conveyors, de-watering screens, vacuum filters, centrifuges, and direct dryers.

22 Mott (C3) shows that natural drainage and dewatering on screens cannot reduce the moisture content of coal below a certain limit, depending on the amount of very fine material present. The finest material fills the interstitial spaces and the water is retained by capillary forces. The application of stronger forces than are brought into play in natural drainage, as in centrifuging, enables a further reduction to be effected, but with the smallest sizes heat only is really effective. If the finest dirt is removed, *e.g.*, by froth flotation, drainage is facilitated.

23 Drainage hoppers are the simplest means of dewatering, but their cost and the space required has led to their replacement by dewatering screens, of which there are several types. Screens are cheaper and quite efficient, but some form of filter is required to dewater slurry, or a froth flotation concentrate, adequately. Centrifuges are efficient and not very costly with fine coal, but they are unable to deal with slurry. Filters are especially suited to slurry treatment and have been used extensively for flotation concentrates, reducing the moisture content to about 15 per cent.

24 To prepare coal for pulverised-fuel firing, or to reduce the moisture content of slurry to below 15 per cent., heat drying alone is satisfactory. Flotation concentrates have been dried commercially to about 6 per cent. of water in dryers.

25 A rational scheme for dewatering washed coal is suggested by Campbell (C1) as follows :—

(*a*) Dewater the fine coal above $\frac{5}{8}$ in. by natural drainage.
(*b*) Centrifuge the coal from $\frac{5}{8}$ in. to 48 mesh.
(*c*) Dry the slimes (48 mesh to 0) by heat.

This scheme is being put into practice at a washery being constructed at Pittsburgh. It sounds complicated, but it should certainly be effective.

(*f*) *Drying of Brown Coal*

26 The ordinary methods of dewatering bituminous coal, by screens, filters, or centrifuges, are only applicable to the removal of the adventitious moisture, and the inherent moisture cannot be removed except by heat. The moisture in brown coal, which may amount to 40 per cent., is inherent, and can only be removed by the application of heat. Heat-dryers of the usual type consist of

rotating cylinders or, if vertical, of stationary cylinders, with some means of causing a slow descent from one level to another. Hot flue gases travel in the opposite direction to the coal.

27 Such appliances may cause considerable fracture of the coal, especially of brown coal. To reduce the amount of breakage a method is used in Austria in which the coal is heated by steam in an autoclave at a pressure up to 15 atmospheres; the temperature is retained for a period of $1\frac{1}{2}$ to 2 hours; the pressure is then released, and air is passed through to dry the coal.

28 The success of a small trial plant of two autoclaves has led to the erection of a plant of eight autoclaves to produce 560 tons of dried fuel per day with a moisture content of 14 to 15 per cent. The steam released from one autoclave is used in a second one and the steam consumption is only 0.6 to 0.7 Kg. per Kg. of water removed. By the careful use of waste steam the heat consumption is only 460 cals. per Kg. of water evaporated.

29 In treatment, the coal contracts and the contraction prevents the re-absorption of water after drying.

DISCUSSION

WEDNESDAY, SEPTEMBER 26 (MORNING)

Section C

COAL TREATMENT

(*a*) Cleaning; (*b*) Drying; (*c*) Briquetting

Chairman: PROFESSOR R. V. WHEELER

The General Report was presented by Dr. R. W. Chapman.

DR. R. LESSING (Vice-Chairman, Great Britain), opened the discussion and said that the work done during the last few years had marked a very considerable step forward and a great advance towards the rejuvenation of the coal industry. During the last three or four years the cleaning of coal without the addition of water had made great progress, particularly in this country; a certain amount of progress had been made in America before then. It would be a very useful outcome of the discussion if the claims made for the two kinds of cleaning coal, *viz.*, wet washing and dry cleaning were considered, even if the point could not be settled as to which was the better. Major Appleyard in his paper pointed out that dry cleaning was not yet applicable without appreciable losses where very clean coal was required, but was mainly intended for the partial removal of the refuse to about 4 or 5 per cent. above the fixed ash content in the coal. That was the position to-day, although no doubt advances would be made. The considerations applying to the wet and the dry processes were very similar and it should be possible to make some interesting comparisons between them, but the comparisons must be on a relative basis. The most important point in any such discussion, however, was cost, and upon that some information would be welcomed.

MR. G. LAMBOURNE (Great Britain) said the problem before the technicians was to evolve some system by which small coal could be cleaned, at a cost which could easily be borne by the producer, to a state of cleanliness which would give the user value for his money. The advantages of dry cleaning came under three heads; and he spoke as a fuel technologist who had a good knowledge of the practical side of coal cleaning and who had recently had a very intimate knowledge of the practical and the research side of dry cleaning. In the first place, on the question of cost; wet cleaning was efficient, but it was expensive. In the case of two such washeries in Durham and South Wales, the cost of wet cleaning coal was 3s. 4d. and 1s. 2d. per ton respectively, and, although Dr. Chapman in his paper referred to a cost of 3d. per ton, washeries where that was possible

were very few and far between. On the other hand, the speaker claimed that the cost of dry cleaning could be brought to below 3d. per ton; that figure related to actual practice in cleaning small coal, and it included both capital and operating costs. The advantage to the consumer was considerable because in one case of a consumer using about 1,000,000 tons per annum, he had gone into the matter and found that by dry cleaning the coal an increase in the calorific value of 7 per cent. was obtained and in another case 9 per cent. Moreover, the ash content was 1 per cent. below the ash content of the shale in the coal, and he claimed that this was very efficient dry cleaning. Dry cleaning was preferable to wet washing because it was effective in dealing with the whole of the coal, whereas wet washing could not deal with the fines. He believed it was a recognised fact that wet washing could only deal with certain sizes. Some screened before washing, and others washed without screening; but he had heard that this latter process necessitated the extraction of the very fine coal if efficient washing was to be obtained and the slurry difficulty was to be overcome. That was the second advantage of dry cleaning, and the third was that it satisfied the necessity for a low moisture content. Dry cleaning could provide modern coke ovens with a dry coal, and so decrease the coking period and at the same time enable the coke oven owner to use coal which he would otherwise have to dump or leave underground. On the relative merits of the two processes he rather felt that Dr. Chapman's remarks in the paper indicated insufficient contact with the processes he described. As a matter of fact, there were merits in both processes, some of which were designed with a specific object and others in consequence of a peculiar kink on the part of the inventor. One particular dry cleaning system with which he had been closely connected for four years was a method based on a kink, but it was a kink which had been developed as the result of years and years of experience in the concentration of minerals. To extract the maximum percentage of ash from coal involved grinding the coal to the finest possible state because the ash was bound up with the coal. He had recently dry cleaned coal of a size of $1\frac{1}{2}$ in. to 0, coal which contained inseparable ash amounting to 13·8 per cent., but which after grinding to $\frac{1}{2}$ in. was reduced to 8 per cent. Wet washing could not get down to within 2 per cent. of the fixed ash whereas with the dry cleaning process to which he had referred he had got down to 1 per cent. of the fixed ash, by taking the coal all in from 1 in. to nothing as against the limitation of the wet process as regards fines. As to the cost of working such a process, local conditions affected the result and it was impossible to bring the operating costs to a uniform basis.

Prof. Douglas Hay (Great Britain) spoke as a mining engineer who not only had to decide the type of plant to install but also had to operate it in such a way as to obtain the results desired. In South Yorkshire practically the whole of the slack and small coal passing $\frac{1}{2}$ in. mesh was carbonised in high temperature ovens.

It contained, in its raw condition, about 15 per cent. of ash and some 50 per cent. of it would pass $\frac{1}{10}$ in. It, therefore, presented a problem in washing, and in his own case he had to treat this slack to make it suitable for a new oven plant which was under construction, using modern silica brick, which imposed finer limits as regards moisture than did the older types of plant. The problem, therefore, was to bring the ash content in the washed coal down to 6 per cent. and the moisture down to 9 per cent. and preferably 8 per cent. Having carried out numerous experiments to see which type of washing plant was likely to give the best results, the conclusion arrived at was that none of the dry-cleaning processes quite gave the desired efficiency, whereas several of the wet washing processes did. The conclusion was also arrived at that the key to success was the removal of a certain proportion of the fine dust passing 1 mm. mesh before washing and using that dust on the premises for power production or in some other way. No difficulty had been experienced in getting the moisture content in the final product below 10 per cent. and the ash percentage below 6 per cent., and by the use of de-watering screens there was no need for expensive centrifuges or filters or a thermal dryer, all of which were comparatively costly to maintain. Another problem in wet washing was the proper clarification of the washing water in circulation, but this difficulty could be overcome by the use of suitable clarification tanks. Finally Prof. Hay said that in the case of the plant he had referred to, the question was considered whether a central washery should be installed to deal with the coal from the number of collieries concerned in the scheme or whether individual plants should be installed at each colliery. The decision to install individual plants was influenced by the fact that in the event of new developments in such washing plants it would be simpler to try them out at individual collieries, instead of having to scrap, perhaps, a very large central plant.

Dr. R. Lessing (Vice-Chairman, Great Britain) said his attention had been called to the statement in his previous remarks that a limit of 4 or 5 per cent. above the inherent ash was the possible limit of dry cleaning. Nothing was further from his mind. Continuing, Dr. Lessing referred to a process of coal cleaning which he said has not yet been made public, and which was dissimilar from any of those discussed so far, in that it was entirely independent of the size of the coal. Thus it was necessary to deal with one factor only, specific gravity, instead of the two factors of specific gravity and size. This particular process, however, was not based on a "kink" in the brain of the inventor, mentioned by a previous speaker, but on a thorough scientific investigation, which originally was not intended to deal with the practical problem but was directed towards elucidating the distribution of the mineral matter in coal. The process used as the means for the separation of the refuse from the clean coal was the very criterion which we had been in the habit of employing for testing the composition of raw coal, *viz.*, the ordinary float-and-sink test. In the past, there had been considerable

difficulty in the commercial application of such a process on a large scale, but these difficulties had now successfully been overcome, and it was now possible to obtain quantitatively the possible maximum yield of truly clean coal from coals in which the ash and refuse were in mechanical admixture with the coal, which was the case with all small coals. It was not quite so easy in the case of large coals, and it might be found more advantageous to crush the coal where the highest possible purity was required. By this process, however, it was possible to get the ash content down to between 1 and 3 per cent., while the free moisture was less than 5 per cent.

The process consisted in introducing the raw coal into a dense liquid, such as a calcium chloride solution. It was not quite as simple as it appeared on the surface, because in order to comply with commercial requirements it was essential to remove the calcium chloride solution from the coal in such a manner that it could be recovered in its original strength without any appreciable loss so far as the cost of cleaning was concerned. This had been found possible by removing, in the first instance, the fine portion of the coal, which contained practically all the fusain and which was in character, both chemically and physically, entirely different from the pure coal. In order to make the process economic, however, it was necessary to carry it out in such a manner that these fines were recovered in a condition in which they could be used directly and without further grinding for coal dust firing. This was done with such accuracy and such a close cut that although the whole of this fine material was recovered, the coarse material sent to the gravity cleaning unit contained no more than a fraction of 1 per cent. of material passing 50 mesh, or having a maximum diameter of $\frac{1}{4}$ mm. Discussing the question of expressing the efficiency of processes, Dr. Lessing suggested that it would be better for any cleaning process to take the calorific value of the raw coal and express the efficiency by assessing the calorific value of the marketable products obtained as a percentage of their total value. In the process mentioned, from a slack passing a $\frac{3}{16}$ in. screen, and containing 15-20 per cent. of ash, 75 per cent. of its calorific value was recovered in the form of a coal containing 2 per cent. of ash, and 22 per cent. of a fuel powder containing about 14 per cent. of ash. Only 3 per cent. of calorific value was lost as refuse.

Mr. C. W. H. Holmes (Great Britain) said we had been told by Mr. Lambourne that the millennium had arrived so far as dry cleaning was concerned and we had also been told by Prof. Douglas Hay that it had not. Personally he had been interested in the dry cleaning of coal for several years, and he wished first of all to draw attention to an error which it appeared Dr. Lessing had made in reading Major Appleyard's paper in saying that coal could be dry cleaned down only to 4 or 5 per cent. above the fixed ash. That was a general statement relating to the treatment of unsized coal. In dry cleaning coal that had been sized down to two, or possibly more sizes, results at least comparable with those obtained with wet washing could be obtained and these were better than

4 or 5 per cent. above the fixed ash. Two papers had been presented dealing with pneumatic separation, one by Mr. Raw and the other by Major Appleyard. The theory was gone into at considerable length in Mr. Raw's paper, but Mr. Raw knew that he disagreed with him fundamentally about his theory. So far as the conditions dealt with in that paper were concerned, however, they could be brought under three heads, *viz.*, the bed, the air and the motion. As Mr. Raw had pointed out, it was quite impossible to have the conditions named in the paper with an open bed because there was then too great an escapement. On the other hand it was absolutely essential to have some escapement, but conditions varied gradually all down the scale. The other factor of most importance was the motion applied to the separator, and it was interesting to note the figure mentioned for the maximum motion, *viz*, 400 oscillations for $\frac{1}{2}$ in. through. It rather seemed that that was the motion above gravity acceleration, which however desirable on the separator would be very undesirable on the structure. Figures were given in Major Appleyard's paper showing that in the treatment of unsized coal the improvement gradually fell off just as it did with wet washing, and it was common knowledge that in a number of washing processes the re-treatment of the fines in a re-wash box, such as the Baum jig or the Rheolaveur trough, was carried out; and personally he saw no discredit in giving a certain amount of preferential treatment to the fines in the process of dry cleaning, because the fines were notoriously most dificult to treat by any process. The question as to what improvement could be made in the treatment of unsized coal depended primarily on the coal. Frequently a striking improvement could be made in the County of Durham whereas the improvement in the majority of South Yorkshire coals would not be very great. This was associated with the ash distribution in the coal, and each case must be judged upon its merits. There was no best method for washing coal, neither probably was there any best method for treating coal dry. Summarising the essential conditions in any form of pneumatic separator; there must be the maximum fluidity and density of the bed coupled with the minimum of velocity of escapement of the air with regard to the smallest particle there might be in the bed. So far as the supply of air pressure was concerned, various statements had been put forward regarding the relative advantages of continuous or pulsating pressure in a bed containing a mixture of particles. It was extremely difficult, however, to maintain either. In the case of continuous pressure there was a distinct valve action with lift and fall of the bed which gave, to a certain extent, a pulsating action. On the other hand, it was impossible to maintain the pulsations through the bed with the intensity with which they left the pulsator; so that the conditions in the two cases tended to be rather similar.

Mr. R. A. Mott (Great Britain) remarked that in the paper on froth flotation the authors suggested that instead of cleaning all coal below 10 mm. or $\frac{3}{8}$ in. by various washing processes, only that portion which was less than 3 mm. or $\frac{1}{8}$ in. should be cleaned by

froth flotation. It was a moot point whether froth flotation processes in general could clean coal of such a large maximum size as $\frac{1}{8}$ in. It used to be claimed that the maximum size was $\frac{1}{10}$ in. but from figures which he had been examining it seemed that the maximum size was more often $\frac{1}{20}$ in. It was well known that the advantage of froth flotation was that it had no lower limit of size which could be treated, but one of the great disadvantages which had prevented its wider adoption was the fact that the concentrates could not easily be de-watered. That was due to the fact that the maximum size of particle which could be treated was very small. It was worth while considering, therefore, what factors were concerned in limiting the maximum size of particle which could be treated by froth flotation. In these processes, in which the air was added to the oil and coal mixture by agitation with a large fan, it seemed clear that the turbulence produced dislodged air bubbles from the larger coal particles, which, therefore, did not float. The processes which admitted compressed air at the bottom of the cell had the advantage of less mechanical disturbance, but the difficulty had been most successfully solved, in his opinion, in the vacuum flotation process associated with the name of Mr. Francis Elmore. In this process the air bubbles were produced by the operation of a vacuum and were produced from the air dissolved in the water and from the gases occluded in the coal. The bubbles were produced without any mechanical agitation, and precautions were taken to prevent turbulence, so that once the air bubbles had been attached to the large coal particles they would not be dislodged. In this way it had been found experimentally that pieces as large as $\frac{1}{4}$ in. of certain coals could be floated by the vacuum flotation process and it was easy to float coal of a maximum size of $\frac{1}{8}$ in. The advantage of this was fairly obvious, because the process gave a product which could be more easily de-watered.

Certain other advantages of the vacuum flotation process—if better known—might make cleaning by froth flotation more popular. For example, the froth containing the clean coal overflowed from the top of a cone-shaped vessel and therefore little dirty washing water passed over. The absence of slimes from the washing water facilitated dewatering and resulted in a cleaner product, or, in other words, a greater percentage recovery of a given quality of coal could be made. Variation in the quality of the cleaned coal was contro led by adjustment of the vacuum applied, which enabled the middlings to be recovered or discarded. Dewatering was improved by the application of the vacuum available. One other point was the low power requirement compared with those froth flotation processes requiring violent agitation.

Dr. Tomaïdes (Austria) called the attention of the Conference to the fact that Dr. Fleissner, one of the authors, had died since his paper was prepared, and added that the process described in his paper had been proved most successful in the treatment of Austrian lignites. He offered to answer any questions that might be asked with regard to this paper.

Dr. J. A. Roelofsen (Great Britain) speaking from experience of the ordinary wet washing process and without any experience of dry cleaning, said that coke oven people desired a coal as dry as possible and containing as little ash as possible. As regards the removal of surplus water, there was a process which had been in use for some years, and he was surprised it had not been mentioned in any of the papers or in the discussion. He was associated with two of these plants which were of the pulsating types, and they dealt with a variety of coals which arrived at the coke ovens from a number of collieries, 20 to 30 miles away. The coals contained from 10 to 24 per cent. of ash which had to be removed and it was reduced to 6 or 7 per cent. in the pulsating washer, the water being taken out without producing any slurry to speak of. The plant consisted of a series of hoppers overflowing into a trough. The coal, in the first instance, was crushed from 4 in. to 1 in. down to dust. The whole of it was floated with the washing water into the hoppers. When the coal accumulated in the hopper, the water overflowed by way of the troughs into a sump and was used again. The hoppers were of 120 tons capacity, and were allowed to drain through two columns of perforated metal 2 ft. in diameter and 24 to 25 ft. in height, the height of the hoppers. The surplus water drained through these perforated columns and came out perfectly clear at the bottom and was used over again. There were no mechanical moving parts, and the process was extremely simple. It brought down the water content of the coal to about 8 per cent., which was quite a good performance. It took 48 hours for each hopper to reach this condition, and there was very little additional expense involved as it was necessary to store three days supply in any case, and some storage accommodation would be required for that. There were 20 such hoppers of 120 tons capacity each; the drainage columns lasted for many years and a good product was obtained for the coke ovens.

Mr. A. Grounds (Great Britain) said he wished to correct an impression that seemed to exist among those in the mining industry, and also among fuel technologists, that wet washing and dry cleaning were antagonistic to each other. That was not so at all. At the Bradford colliery in Manchester there was a group of spiral separators which were dry cleaning coal, but the middlings fraction obtained was re-crushed and treated on four concentrating tables, a combination of wet washing and dry cleaning, which was very efficient and dealt with the smallest coal. In the Lewis Merthyr colliery in South Wales both processes were also used, and the wet washing people were anxious to co-operate with the dry cleaning people so that the greatest advantage could be obtained from both processes. As a matter of fact, at the present time one of the largest makers of wet washing plants was contemplating installing a dry cleaning plant as a roughing plant preliminary to the treatment of the coal by the wet process. Therefore, the two processes were not antagonistic but complementary to each other. His one regret about all the papers was that so little was said about the cost of

working these various processes, and he would have welcomed comparative costs of operations under more or less similar conditions. Whilst in the wet process there was the difficulty of dealing with the slurry, in the dry cleaning process there was the dust problem, and although it was not a very courageous attitude to adopt he feared that some mining engineers had adopted the view that "better the devil we know than the devil we do not know." That was not the correct attitude to take up, and he believed the wet cleaning people themselves would be very pleased to hear what had been done by the dry cleaning people as regards the dust problem.

Mr. A. S. Brentnall (Great Britain) said that he had had some experience with one of the latest types of dry cleaning plant, cleaning slack below $1\frac{1}{2}$ in. in three sizes, to $\frac{1}{2}$ in., to $\frac{1}{8}$ in. and to $\frac{1}{64}$ in. In the first case the amount of free shale could be reduced to 1 or 2 per cent., in the second 2 or 3 per cent. and in the third 4 or 5 per cent. There were, however, certain fluctuations in the operation of the plant which would have to be overcome. Possibly these were due to fluctuations in the raw coal, or perhaps to stratification of light and heavy material in the bunkers. It could never be expected that coal from several collieries, or even one, would be of a constant uniform quality. Before dry cleaning could be considered fully efficient, therefore, these variations would have to be eliminated. As the separation was not complete, it was necessary to recirculate about 10 per cent. of the product. The plant was put down to make a coking slack having a maximum of 8 per cent. of ash and that result was often obtained, but owing to the variations he had mentioned, it could not at the moment be relied upon. He was confident, however, that this would soon be realised. About 10 to 15 per cent. of dust was aspirated and the intention was to carbonise some of this into low temperature fuel, but at present it was being sold separately as pulverised fuel or put back. The ash content of this dust was reduced by aspiration from 14 to 10 per cent. Very considerable reductions in the sulphur content of the slack were effected by the removal of pyrites.

This concluded the Discussion on Section C.

SECTION D

STORAGE AND HANDLING OF SOLID FUELS BY THE USER

D1 METHODS OF CONTROL, PREPARATION, HANDLING AND STORAGE OF COALS BY THE NATIONAL RAILWAYS OF BELGIUM.

D2 STORAGE AND HANDLING OF LEMATANG ADMIRALTY COAL.

D3 STORAGE, HANDLING AND TRANSPORT OF OMBILIN COAL AT EMMAHAVEN.

D4 THE STORAGE AND HANDLING OF SOLID FUELS BY THE USER.

THE NUMBERS ARE THOSE GIVEN TO EACH PAPER
FOR USE AT THE FUEL CONFERENCE

MÉTHODES DE CONTRÔLE, PRÉPARATION, MANUTENTION ET EMMAGASINAGE DES CHARBONS À LA SOCIÉTÉ NATIONALE DES CHEMINS DE FER BELGES

(METHODS OF CONTROL, PREPARATION, HANDLING AND STORAGE OF COALS BY THE NATIONAL RAILWAYS OF BELGIUM)

SOCIÉTÉ NATIONALE DES CHEMINS DE FER BELGES

H. CHENU

*Paper No. D*1

CONTENTS

NATURE OF FUEL—METHOD OF BLENDING—DESCRIPTION AND OPERATION OF GRADING PLANT—HANDLING AT DEPOTS—CONTROL OF COAL—BUYING BY QUALITY OF FUEL
LIST OF EXPERTS.
RÉSUMÉ

Importance du réseau

La Société Nationale des chemins de fer belges exploite un réseau de 7.699 km. qui représente la presque totalité des voies ferrées de la Belgique.

Le nombre de tonnes-kilomètres brutes remorquées annuellement est de 32 milliards environ. Elles représentent 111 millions de kilomètres de parcours de locomotives.

Le tableau ci-après permet de comparer, au point de vue de l'importance du travail de remorque des convois, l'exploitation de la Société Nationale des chemins de fer belges à celle de quelques grands réseaux européens pendant l'année 1926.

Désignation des réseaux	Kilomètres de voies principales exploitées	Tonnes-kilomètres remorquées (trains)	Kilomètres-locomotives parcourus (manœuvres comprises)*
Allemagne	77.088	224.100.000.000	730.055.000
L.M. & S. Ry.	21.489	—	253.457.000
L. & N.E. Ry.	18.512	—	180.474.000
P.L.M.	14.846	—	138.869.000
Chemins de fer belges ...	7.699	32.016.000.000	110.697.000
Great Western Ry.... ...	10.222	—	107.195.000
État Français	13.077	—	80.246.000
Nord Français	6.454	—	80.240.000
Southern Ry.	6.703	—	73.077.000
Est Français	9.174	—	72.661.000
Chemins de fer fédéraux Suisses	3.862	9.208.000.000	39.380.000
Midi Français	5.479	—	35.096.000
Alsace-Lorraine	3.654	—	34.876.000

* Les chiffres de cette colonne ont été établis en supposant, pour tous les réseaux, que l'heure de machine de manœuvre corresponde à 4 km. de parcours.

Nature des combustibles consommés

Les chemins de fer belges consomment annuellement, pour le travail de leurs locomotives, un tonnage total d'environ 2.400.000 tonnes de combustibles divers. Ce chiffre représente 9 pour cent de l'extraction totale annuelle des charbonnages belges qui a été de 27.750.000 tonnes en 1927.

Comme le font généralement les exploitations de transports par fer qui comprennent, dans les limites géographiques de leur réseau, des bassins charbonniers importants, les chemins de fer belges utilisent des types de foyers de locomotives appropriés à la nature des combustibles produits dans leur réseau, c'est-à-dire en Belgique. Comme on le sait, les combustibles extraits des mines belges comprennent une proportion relativement élevée de charbons de petites dimensions, c'est-à-dire de charbons menus. Les charbonnages belges sont d'ailleurs amenés à utiliser une partie de leurs poussiers dans la fabrication de briquettes.

On conçoit, dès lors, que les chemins de fer belges aient cherché à utiliser dans la plus large mesure possible les charbons menus qu'ils peuvent trouver sur place à bon compte de préférence aux charbons en roche ou aux briquettes, lesquels atteignent généralement des prix dépassant sensiblement celui qui correspondrait à leur valeur calorifique comparée à celle des menus.

Cependant, l'usage absolument exclusif de charbons menus dans

les foyers de locomotives aboutirait à une exploitation peu économique de la traction des trains, le charbon menu conduisant, toutes choses égales, à une puissance inférieure de la locomotive par m^2 de surface de grille.

Aussi les chemins de fer belges utilisent-ils d'une façon générale des foyers mi-profonds permettant l'emploi, soit de combustibles menus sous faible épaisseur de feu, soit de combustibles en morceaux, criblés ou briquettes, brûlant sous une assez forte épaisseur et permettant ainsi la combustion éventuelle d'un poids élevé de charbon par m^2 et par heure, soit encore simultanément du menu et du gros en proportions variables, ce qui rend possible la réalisation de toute la gamme des régimes de combustion situés entre les deux régimes extrêmes.

Un tel état de choses répond bien aux exigences du moteur de traction dont la puissance, dépendant de la charge et de la vitesse du convoi ainsi que du profil de la ligne, est essentiellement variable. Il est donc fait usage du combustible menu chaque fois que la puissance de remorque exigée en autorise l'emploi, ou, plus exactement, la chauffe de la locomotive est réglée *à tout instant* de façon à ce que la proportion de menu utilisée corresponde à la puissance à réaliser par le moteur. C'est ainsi que le même type de moteur utilisera exclusivement du menu à certains trains faciles et du criblé ou des briquettes à d'autres trains ou sur d'autres lignes; la même locomotive, disposant sur son tender des deux espèces de combustibles, est amenée aussi à consommer, au même train, du menu sur les tronçons de ligne à remorque aisée et à faire usage de morceaux peu après sur d'autres tronçons.

Ce principe, évidemment élémentaire, qui consiste à faire, *à tout moment*, un choix de combustibles tel que l'on obtienne, en fin de compte, la calorie-vapeur au prix de revient minimum, peut paraître plus théorique que pratique, et l'on peut se demander s'il est possible d'amener les 5.000 mécaniciens et les 5.000 chauffeurs roulant sur le réseau belge à faire toujours, parmi les combustibles divers qui sont à leur disposition sur leur tender, le choix judicieux et économique que l'on escompte, alors qu'ils devraient être plutôt tentés de faire choix des combustibles de meilleure qualité et coûtant le plus cher. On y est arrivé cependant en leur fixant, après une étude faite sur chaque train, les méthodes de chauffe à suivre; en les rationnant, avant le départ, aussi exactement que possible et, enfin, en les soumettant à un régime très spécial de primes d'économie de combustibles.

Dans ce régime, le mécanicien et le chauffeur disposent, pour chaque

train ou série de trains analogues, d'une allocation par tonne-kilomètre remorquée exprimée en kilogrammes de charbon-type. Ce charbon-type, qui a la valeur 1, correspond à un charbon composé de proportions déterminées de menu et de gros et son prix est approximativement le prix moyen des combustibles consommés dans tout le réseau. Tout combustible délivré au machiniste est frappé d'un coëfficient de valeur différent de 1 et proportionnel à son prix. C'est ainsi que si le mécanicien charge, sur son tender, 1.000 kg. d'un combustible qui a été payé 1,4 fois le prix du charbon-type, ce combustible sera caractérisé par le coëfficient 1,4 et le mécanicien sera censé avoir reçu 1.400 kg. de charbon-type. Inversement, si le mécanicien fait charger 1.000 kg. d'un charbon ne coûtant que les 80 pour cent du prix du charbon-type, la délivrance ne lui est comptée que pour 800 kg. Il en résulte que le mécanicien et le chauffeur ont un intérêt constant à se montrer parcimonieux des combustibles à prix élevé et à n'y recourir que dans les limites des exigences de leur horaire et de la charge qu'ils remorquent.

L'efficacité des moyens mis en œuvre dans ces dernières années pour atteindre le but poursuivi apparaît par les chiffres suivants. En 1919 la proportion de charbons en roche et de briquettes consommés était de 65,5 pour cent; cette proportion n'était plus que de 17,18 pour cent en 1927, bien que, depuis 1919, la vitesse et la charge des trains aient été en progression constante. Dans ces 17,18 pour cent, les briquettes figurent pour 12,47 pour cent.

En résumé et contrairement à ce que font la plupart des réseaux, les chemins de fer belges consomment en majeure partie des combustibles menus et le tonnage annuel consommé dans cette catégorie est de 2.000.000 tonnes environ.

Les dimensions de ces menus vont de 0/30 à 0/70. La teneur en matières volatiles qui, après des essais précis et suivant les données d'une longue expérience, a été reconnue la plus favorable, est de 18 à 18,5 pour cent.

MOYENS EMPLOYÉS POUR RÉALISER LE COMBUSTIBLE LE PLUS AVANTAGEUX

Origines des combustibles menus.—Les 2.000.000 de tonnes de menus consommés annuellement sont généralement fournies par les charbonnages belges.

Les bassins charbonniers belges sont producteurs d'une gamme très étendue de diverses qualités de charbons, la teneur en matières volatiles variant de 9 à 32 pour cent. Or, le charbon menu

que les chemins de fer belges veulent consommer dans leurs locomotives doit avoir, pour répondre aux exigences de rendement et d'économie définies par les essais et l'expérience, des caractéristiques bien précises, notamment en ce qui concerne la teneur en matières volatiles qui, ainsi qu'il est dit plus haut, ne doit pas s'écarter des limites 18 à 18,5 pour cent. Il ne serait évidemment pas possible de trouver une mine belge qui, à elle seule, fournirait la totalité du combustible menu possédant exactement les caractéristiques requises. Il est donc nécessaire de recourir à plusieurs mines, même à celles qui extraient des combustibles dont les caractères s'éloignent des conditions optima qu'on veut réaliser.

Au surplus, les chemins de fer belges désirent s'alimenter à toutes les mines belges, c'est-à-dire à tous les bassins. Ils sont ainsi amenés, non seulement à acquérir des composants très différents en dimensions: des 0/10, des 0/30, des 0/50, des 0/70, des braisettes, etc., mais, dans chacune de ces catégories, ils obtiennent toute la gamme des charbons, des plus maigres aux plus gras. Le nombre de fournitures différentes alimentant simultanément les chemins de fer atteint ainsi normalement 200.

Pour arriver à la réalisation du menu idéal escompté, les commandes sont réparties entre toutes les mines de telle sorte que, compte tenu des caractéristiques propres aux fournitures de chaque mine et relatives à leur teneur en matières volatiles, à leur teneur en cendres, à leur pouvoir agglutinant, à la fusibilité de leurs cendres et aux dimensions de leurs composants, on obtienne par leur mélange, supposé parfait et homogène, les caractéristiques que l'on s'est fixées à l'avance.

Mais ce menu idéal doit être distribué en une centaine de points de consommation répartis dans tout le réseau, c'est-à-dire dans les dépôts de locomotives et les gares importantes.

La question se pose donc de savoir si le mélange préalable et indispensable doit se réaliser au point de consommation, c'est-à-dire au dépôt des locomotives, ou s'il n'est pas préférable d'effectuer le mélange dans une ou plusieurs grandes centrales situées entre les 200 origines et les 100 points de consommation.

Ce nombre particulièrement élevé des origines et des points de consommation indique immédiatement que cette seconde solution est la seule admissible. L'installation d'un mélangeur en chaque endroit de consommation représenterait un capital considérable. En outre, pour obtenir en chacun de ces points le combustible de la qualité voulue, il faudrait y expédier un nombre très élevé de fournitures diverses, chacune d'importance forcément réduite, ce

qui, dans la pratique, conduirait malgré tout à un combustible final s'écartant notablement du combustible préalablement défini. Enfin, l'irrégularité inévitable des livraisons des charbonnages nécessiterait, à côté de chaque mélangeur local, un stock suffisant de chacune des nombreuses origines, ce qui imposerait l'aménagement de magasins encombrants et coûteux.

Fig. 1. Représentation schématique du rôle et du champ d'action des centrales de mélange.

Les chemins de fer belges ont donc trouvé préférable de recourir au mélange préalable dans quelques grandes centrales situées en divers points du réseau.

Ces centrales de mélange sont au nombre de 4, chacune d'elles

produisant journellement 1.200 à 1.500 T. de charbon mélangé, de charbon "fini," si l'on peut dire. Cette production journalière peut atteindre toutefois 2.000 T. dans chaque centrale.

La recherche de la situation la plus favorable de ces centrales a fait l'objet d'un examen attentif. Il importait, en effet, d'éviter le plus possible que du charbon provenant des centres charbonniers belges ou arrivant même de l'étranger par nos ports ou nos gares frontières et se rendant aux centrales de mélange, ne soit obligé de rebrousser chemin vers les lieux de consommation et ne provoque ainsi des parcours supplémentaires des charbons sur le réseau.

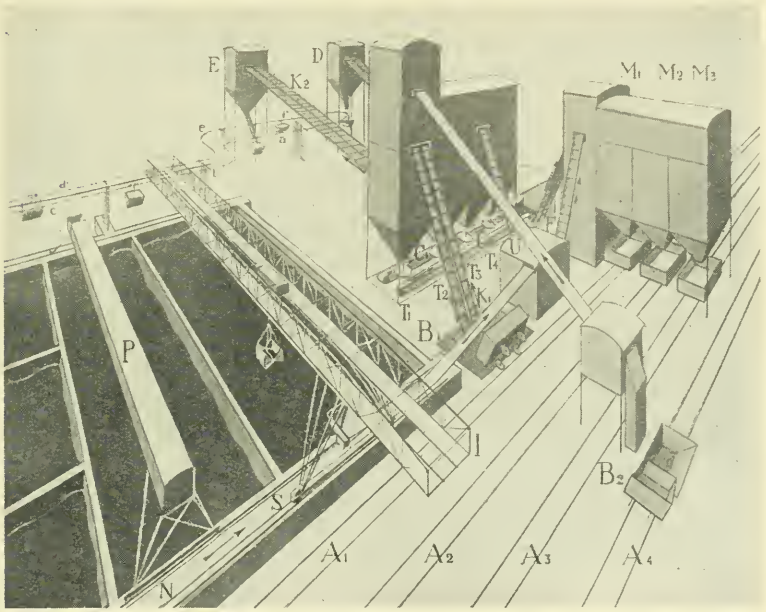

Fig. 2. Représentation schématique d'une centrale de mélange.

La carte de Belgique de la Fig. 1 montre d'une façon schématique comment le problème a été résolu.

Fonctionnement d'une Centrale de Mélange.—Le plan schématique de la Fig. 2 représente une centrale de mélange.

Triage préalable.—Les wagons de charbons venant des mines, sont préalablement triés et rangés dans un ordre bien déterminé avant d'être conduits aux culbuteurs de wagons. Ce triage s'opère sur un long faisceau de voies A_1, A_2, A_3, A_4.

Nous reviendrons plus loin sur la raison d'être et l'importance de ce triage préalable.

Culbuteurs.—Les wagons pourvus de portes latérales sont culbutés sur le culbuteur latéral B_1; les autres, munis de portes frontales, sont amenés sur le culbuteur frontal B_2 dont l'action est beaucoup plus rapide. Dans le cas du charbon sec, la chute de la charge y est pratiquement instantanée. Les deux culbuteurs peuvent d'ailleurs être installés sur une fosse commune.

Mélange.—Le charbon, tombé dans les fosses des culbuteurs, est amené, par des chaînes à godets, au sommet d'un massif de 4 tours T_1, T_2, T_3, T_4. Il est déposé sur une chaîne à râclettes qui se meut horizontalement et le déverse dans l'une ou l'autre des 4 tours suivant sa teneur en matières volatiles. Ces tours sont donc caractérisées par la teneur en matières volatiles du charbon qu'elles contiennent.

A la base de ces tours se trouvent des soles tournantes doseuses permettant de distribuer le charbon sur des courroies C_1 et C_2 suivant un débit réglable à volonté. On obtient ainsi telle teneur finale en matières volatiles que l'on désire et le charbon fini et homogène tombe dans la fosse F.

La réalisation d'une teneur en matières volatiles fixe et constante n'est cependant pas la seule condition à laquelle doit répondre le charbon fini. Il faut aussi veiller à ce qu'il réponde aux caractéristiques voulues relativement à la teneur en cendres, aux dimensions, au pouvoir agglutinant et à la fusibilité des cendres. Ainsi qu'il a été dit plus haut, les commandes sont réparties entre les diverses mines et les expéditions sont distribuées entre les 4 centrales de façon à ce que la moyenne des charbons y arrivant donne les caractéristiques exigées.

Il faut donc que les wagons arrivent aux culbuteurs suivant une alternance déterminée qui assure, par pénétration des charges successives dans les tours T, le mélange des charbons de diverses caractéristiques, de telle sorte que les charbons tombant des tours T sur les courroies C soient identiques et ne diffèrent plus que par leur teneur en matières volatiles. C'est cette alternance des wagons qui nécessite leur triage préalable sur le faisceau des voies A_1, A_2, A_3 et A_4.

Distribution et mise en stock.—Le charbon fini, déversé dans la fosse F, y est repris par une chaîne à godets qui le déverse dans les 3 tours distributrices, M_1, M_2, M_3. C'est sous ces tours que passent, pour y être chargés, les wagons à destination des lieux de consommation. Si la production de charbon fini dépasse momentanément le

débit des tours M, le charbon est repris de la fosse F par une chaîne à godets, conduit dans une tour D et débité dans des bennes automotrices qui suivent un circuit a b c d e f le long du parc de stockage. Ces bennes se déversent automatiquement à l'extrémité d'un pont roulant P qui distribue le charbon mélangé dans le compartiment qui lui est réservé au parc de stockage.

Ce charbon mélangé peut être repris du stock ultérieurement par un grappin qui, à l'aide du portique I, le dépose sur un transporteur métallique N S aboutissant à la tour U, d'où le charbon est repris par une chaîne à godets pour être finalement ramené aux tours distributrices M.

Lorsque le débit des culbuteurs dépasse la production des tours T, ou lorsque les arrivages de l'une ou l'autre qualité dépassent les proportions requises, il faut stocker ces charbons avant mélange. A cet effet, le parc de stockage, qui a une capacité totale de 20 à 25.000 T, est divisé en un grand nombre de compartiments correspondant chacun à une qualité de charbon déterminée. Le charbon doit y être conduit immédiatement après culbutage sans passer par les tours T. Les deux chaînes à godets K_1 et K_2 le transportent en E d'où les bennes automotrices et le pont P le déversent dans le compartiment qui lui est réservé. L'une ou l'autre des qualités ainsi stockées est reprise en cas de besoin par le portique I, le transporteur N S et la tour U, d'où une chaîne à godets la conduit au sommet des tours T.

Le portique I, en dehors du rôle qu'il joue dans les cas de reprise au stock des charbons avant ou après mélange, constitue en outre un moyen de secours qui peut entrer en action lorsque l'une ou l'autre partie de l'installation est immobilisée pour réparation ou entretien, ou encore dans les cas où, voulant faire face à une augmentation des arrivages, on est amené à forcer le rendement du mélangeur. Il peut servir, en effet, comme simple portique desservant un parc de stockage ordinaire. S'il s'agit de reprendre du mélangé, il peut déverser celui-ci directement dans le wagons destines aux lieux de consommation, sans passer par N S U M. Il peut aussi reprendre du non mélangé et le déverser dans un wagon destiné au culbuteur, sans que le charbon soit obligé de suivre le chemin N S U T.

L'installation est donc très souple et permet d'obtenir un charbon très homogène et très régulier. Les caractéristiques du charbon fini sont fréquemment vérifiées, au cours de la journée, par des prises d'essai opérées à la sortie des courroies C_1 C_2 et analysées sur le champ dans un laboratoire annexé à l'installation.

Le prix de revient actuel du mélange, y compris les frais

d'amortissement et d'intérêt et compte tenu des mises en stock et des reprises, est de 2f70. La production des centrales de mélange devant vraisemblablement augmenter dans l'avenir, ce prix ne pourra que diminuer.

Cette dépense est certainement inférieure au bénéfice résultant de l'emploi d'un charbon homogène, de qualité constante et répondant exactement aux caractéristiques optima fixées préalablement par des expériences de laboratoire, des épreuves en chaudières fixes de locomotives et des essais très longs et très étendus sur des locomotives en service. L'économie de combustible qui y correspond est d'un ordre de grandeur qui dépasse 5 pour cent; ce taux permettrait d'amortir l'installation en moins de 3 ans.

Mais le plus grand avantage que procure le mélange parfait résulte de ce que les mécaniciens et les chauffeurs, disposant toujours d'un combustible de qualité connue, n'éprouvent aucune surprise et aucun mécompte en cours de route. La régularité dans la marche des trains s'en trouve améliorée; les méthodes de chauffe peuvent être mieux étudiées, plus facilement enseignées au personnel et plus rigoureusement respectées; les foyers et les chaudières ont une puissance sur laquelle on peut compter à coup sûr, ce qui permet de tirer un meilleur parti des moteurs. La première centrale de mélange de la Société Nationale des chemins de fer belges fonctionne depuis près de 3 ans et les résultats obtenus ont répondu largement à toutes les prévisions.

Appareils de manutention installés aux endroits de consommation

Dépôts peu importants.—Dans les dépôts de faible importance, le charbon menu provenant des centrales de mélange est emmagasiné dans des parcs construits en béton ou en vieilles billes. Il en est de même des charbons de fortes dimensions ne passant pas par le mélangeur. Quant aux briquettes, elles sont emmagasinées en tas aussi réguliers que possible portant indication, à la chaux blanche, du tonnage et de l'origine. Le déchargement des charbons menus et autres dans les parcs, ainsi que leur reprise des parcs, s'effectue au moyen de grues automotrices à vapeur actionnant des grappins jaugés. La manutention des briquettes s'opère à la main.

Le choix des grues automotrices trouve son explication dans le fait que la manutention des charbons, ne parvenant pas à absorber d'une façon continue l'activité des grues, celles-ci peuvent servir dans le dépôt à d'autres usages, tels que le chargement des cendrées,

la manutention des matières et objects pondéreux, le grappin étant remplacé par un crochet, etc.

Dépôts de moyenne importance.—La grue automotrice est ici remplacée, au chargement du moins, par une grue électrique fixe et pivotante. Les charbons et les briquettes sont chargés dans des wagonnets conduits sous la grue qui les enlève et les déverse dans les tenders.

Dépôts importants.—On fait ici usage d'estacades A pourvues d'un ascenceur B et de culbuteurs C C (Fig. 3). Le charbon menu a été chargé, aux centrales de mélange, dans des wagons spécialisés qui possèdent des fonds inclinés vers les parois latérales percées de trois trémies (Fig. 4) et qui viennent s'aligner sur une voie V voisine de l'estacade. Sur une petite voie v, parallèle à la voie V, circulent des wagonnets qui, en stationnement devant les trémies des wagons

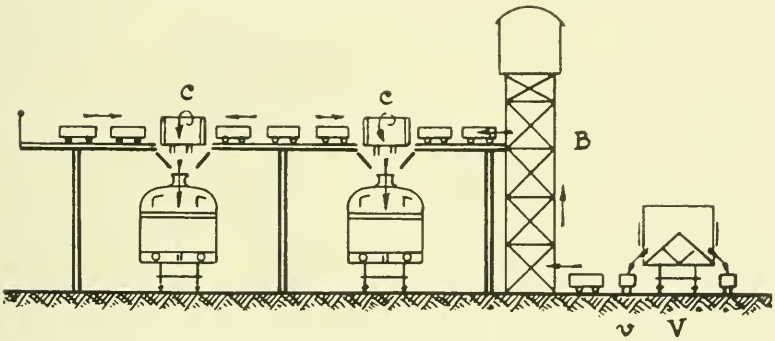

Fig. 3. Estacade de chargement.

spécialisés, sont remplis de charbon et sont conduits alors, par l'intermédiaire de l'ascenceur B au sommet de l'estacade. C'est de là qu'ils sont culbutés en C C au-dessus des tenders des locomotives en chargement sous l'estacade. Quant aux briquettes, elles sont chargées à la main dans les mêmes wagonnets dont les voies longent les tas de briquettes et, conduites au sommet de l'estacade, sont culbutées dans les tenders comme les charbons.

De telles installations paraissent assez rudimentaires, à première vue du moins. Elles donnent cependant des prix de revient extrêmement bas.

En matière de chargement de locomotives, en effet, le prix de revient de la manutention d'une tonne de charbon comprend, outre les postes habituels communs à toute manutention, les frais de stationnement des locomotives et de leur personnel pendant les opérations de chargement. Ces derniers frais sont particulièrement

élevés. Un réseau de chemin de fer cherche toujours, par tous les moyens, à augmenter le parcours journalier de ses locomotives et de son personnel roulant dans le but de diminuer l'effectif des locomotives et du personnel nécessaires et de réduire les consommations de combustibles, les dépenses d'entretien et de réparation des locomotives, ainsi que l'importance des installations des dépôts. La réduction des stationnements des locomotives dans les dépôts est donc un facteur important d'économie et c'est pour cette raison que l'estacade, permettant un chargement très rapide des locomotives

Fig. 4. Wagons spécialités desservant les estacades.

par les petits basculeurs C C, permet d'atteindre finalement des prix de revient très faibles.

Il faut noter, au surplus, que la fréquence des chargements est très variable dans le cours d'une journée. A certaines heures, les locomotives se succèdent de près et il importe que le chargement des premières ne provoque pas des attentes prolongées des locomotives qui suivent. Très fréquemment, le calcul de la durée du chargement qui doit servir à la détermination du prix de revient, s'augmente ainsi de certains délais d'attente. Or, l'estacade, largement conçue en surface, a pu emmagasiner à l'étage un nombre élevé de wagonnets pendant les périodes calmes de la journée, de sorte qu'aux heures

de presse, les wagonnets pleins peuvent être avancés avec grande rapidité sur les culbuteurs.

Il est intéressant de remarquer aussi que, contrairement à ce qui se passe dans beaucoup d'installations à fontionnement irrégulier, où le personnel est mal utilisé aux périodes d'accalmie, les agents d'une estacade travaillent avec un excellent rendement: aux heures peu chargées, ils constituent la réserve de wagonnets pleins au sommet de l'estacade et, aux moments des chargements, ils abandonnent l'alimentation de l'estacade et se consacrent entièrement au culbutage.

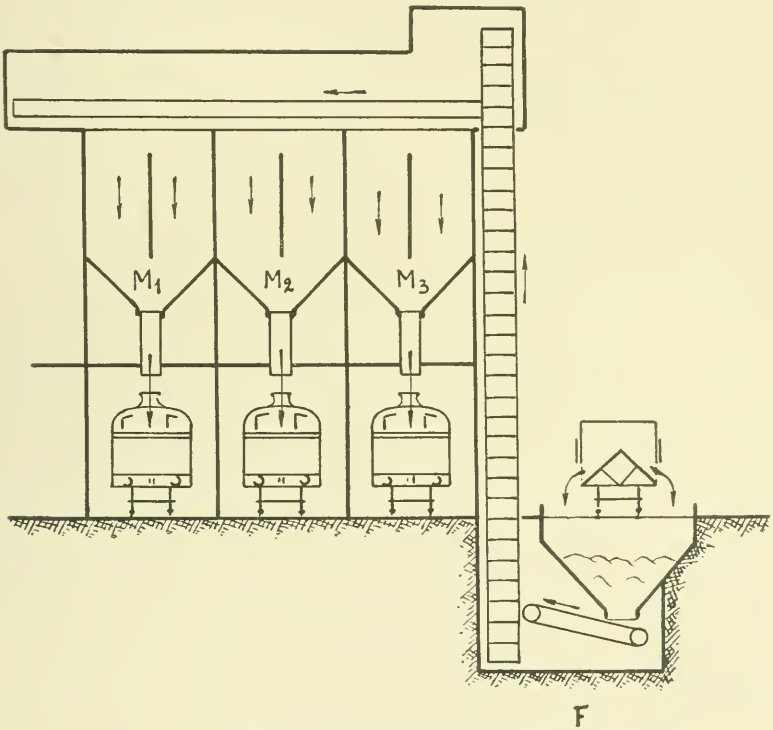

Fig. 5. Tours de chargement.

Dépôts très importants.—La Fig. 5 représente le schéma de tous les chargements utilisés dans les dépôts très importants. Les wagons spécialisés utilisés dans ce cas s'ouvrent latéralement et se vident instantanément dans une fosse F d'où le charbon est repris par une chaîne à godets qui le conduit dans des tours distributrices M_1 M_2 M_3. Le chargement est également très rapide, mais l'installation

est plus coûteuse et ne peut être amortie avec avantage qu'avec de forts débits.

A ces tours est accolée une estacade pour le chargement des briquettes.

ACHATS DES CHARBONS; CONDITIONS TECHNIQUES

Conditions générales.—Les conditions techniques imposées pour les diverses catégories de charbons fournis aux chemins de fer par les charbonnages belges fixent notamment les dimensions des charbons à fournir, la limite inférieure et supérieure de la teneur en matières volatiles, la température de fusibilité des cendres, la teneur en soufre et, éventuellement, le pouvoir agglutinant et la friabilité.

Pouvoir calorifique.—Aucune condition précise n'est généralement imposée relativement au pouvoir calorifique, au pouvoir de vaporisation, à la teneur en cendres et à la teneur en eau.

Ces éléments sont cependant ceux qui préoccupent le plus le consommateur de charbon et le réseau des chemins de fer belges est loin d'en méconnaître la valeur.

Il estime toutefois qu'il est peu pratique d'imposer des conditions fixes à ces divers points de vue au moment de la commande.

Ainsi qu'on le verra plus loin, les chemins de fer belges disposent de plusieurs laboratoires de combustibles parmi lesquels existe, à Bruxelles, un laboratoire central qui est, avant tout, un laboratoire d'étude et de contrôle. Ce laboratoire permet d'effectuer les analyses généralement usitées pour la détermination des divers caractères des combustibles et dispose, en outre, de chaudières fixes de locomotives de types différents munies d'appareils de mesure et permettant d'effectuer des essais de vaporisation complets. C'est dans ce laboratoire que l'on étudie avec soin la nature, la valeur, les diverses particularités des combustibles des nombreuses origines, mines et bassins belges et étrangers susceptibles d'alimenter les chemins de fer belges. Ce laboratoire central détermine le pouvoir calorifique des combustibles à la bombe calorimétrique et le considère comme une caractéristique propre au combustible, caractéristique qu'il dégage de toute influence due à la teneur en cendres, à l'eau ou à tout autre élément susceptible d'être apprécié par d'autres moyens. Le pouvoir calorifique conserve ainsi toute sa valeur relative et permet de comparer avec certitude diverses origines de combustibles. Le pouvoir calorifique déterminé avec plus ou moins de certitude et de précision par les méthodes habituelles et fortement influencé d'ailleurs par les teneurs en cendres, ne peut

avoir de signification absolue et ne peut servir à caractériser une *livraison*. Telle est la raison pour laquelle les chemins de fer belges s'abstiennent d'imposer cette caractéristique lors des commandes ou de la vérifier lors des fournitures.

Pouvoir de vaporisation.—La pouvoir de vaporisation aurait une signification bien plus vague encore, car, même lorsque l'essai est effectué en chaudière *fixe* de locomotive dans des conditions bien déterminées, il dépend d'un très grand nombre de facteurs absolument étrangers à la valeur du combustible et, notamment, pour ne citer que quelques-uns de ces facteurs: 1°: du type de foyer choisi; 2°: du régime de combustion; 3°: du titre de la vapeur, si difficile à mesurer; 4°: de l'état de propreté de la chaudière; 5°: de l'état de propreté des tubes; 6°: de l'état de la grille; 7°: du tirage; 8°: de la capacité de l'opérateur; 9°: de la valeur des appareils et de l'approximation des mesures; 10°: de la capacité du chauffeur.

En ce qui concerne ce dernier facteur d'influence, il est intéressant de signaler qu'à l'occasion d'un concours de chauffeurs,[1] les résultats obtenus par le premier et le dernier chauffeur du classement présentaient un écart de 43 pour cent. Ces chauffeurs travaillaient cependant dans des conditions identiques et disposaient du même charbon.

Et si l'essai de vaporisation s'effectue sur la route, il faut ajouter à ces nombreuses causes d'erreurs celles qui résultent de la variabilité des conditions de remorque des convois et celles aussi qui sont la conséquence des difficultés multiples que l'on rencontre à vouloir effectuer des mesures très précises sur la locomotive en service.

Le pouvoir de vaporisation ne peut donc caractériser, même approximativement, un combustible déterminé.

Teneurs en cendres et en eau.—La valeur exacte d'un combustible déterminé, provenant d'une origine connue, combustible qui a été étudié par le laboratoire central et par le service courant et qui répond à des conditions bien précises définies ci-dessus sous la rubrique "Conditions générales," ne peut plus dépendre que de sa teneur en cendres et de sa teneur en eau.

Rappelons tout d'abord que, dans les locomotives, une teneur trop élevée en cendres ne diminue pas seulement la valeur calorifique du charbon et le rendement de la combustion, ainsi que cela se passe dans toute chaudière fixe, mais qu'elle occasionne ici d'autres pertes très importantes. Elle diminue la *puissance* des locomotives, elle réduit les possibilités des parcours sans arrêts prolongés—d'où résulte un affaiblissement du rendement de l'effectif locomotives—et,

[1] Lors de l'Exposition de Liége en 1905.

enfin, elle augmente les chances d'incidents de la route dus à des défauts de pression.

Les chemins de fer belges imposaient autrefois une teneur limite en cendres lors de ses commandes de charbon. Or, parmi divers charbons qu'il s'agit d'acheter et qui répondent tous à la condition de la teneur limite, certains d'entre eux restent en dessous de cette teneur et, partant, ont une valeur supérieure. La fixation d'une teneur limite fausse donc la comparaison des prix de combustibles analogues. Au surplus, la rigueur avec laquelle l'acheteur exige le respect de la limite garantie expose à des rebuts et des discussions qui contrarient l'approvisionnement régulier et nuisent aux tractations ultérieures.

L'extension prise en Belgique dans ces dernières années par l'abatage mécanique a d'ailleurs accentué les différences existant dans les teneurs en cendres des charbons menus par l'introduction d'une proportion importante de charbons lavés ou mi-lavés.

Ces charbons lavés présentent d'ailleurs cette particularité d'accentuer l'influence de la teneur en eau sur la valeur des divers charbons d'une même catégorie fournis autrefois au même prix.

C'est pour tenir compte, aussi exactement que possible, de l'importance de ces deux éléments, teneur en cendres et teneur en eau, que les chemins de fer belges ont cessé, depuis quelques années, d'acheter les charbons à prix fixe et passent actuellement des marchés d'après lesquels le prix des fournitures est déterminé après livraison.

Le prix discuté avant la conclusion d'un marché est celui d'un charbon défini par les conditions générales spécifiées ci-dessus et répondant notamment à une teneur en matières volatiles située entre des limites bien déterminées. Ce prix n'est qu'un *prix de base*; c'est celui qui correspond à un combustible à teneur fixe en cendres et en eau. C'est ainsi que, pour les menus, ces teneurs sont respectivement de 12 pour cent et de 5 pour cent. Pour les briquettes, elles sont de 9-10 pour cent et de 5 pour cent.

Le prix final de la fourniture dépendra des teneurs réelles relevées dans le combustible au moment de la livraison et sera obtenu par application de l'échelle suivante: par pour cent de cendres au-dessus ou en-dessous du point de départ, le prix de base subit une diminution ou une augmentation de 2,5 pour cent; par pour cent d'eau au-dessus de 5 pour cent, le prix sera diminué de 1 pour cent, sans qu'il puisse être augmenté dans le cas où la teneur serait inférieure à 5 pour cent. Au-delà de 17 pour cent de cendres, le taux de diminution s'élève à 3 pour cent au lieu de 2,5 pour cent.

Une teneur limite supérieure, au-delà de laquelle la marchandise est rebutée, est néanmoins imposée pour tous les combustibles, mais elle est établie de telle sorte que le rebut ne s'impose que très rarement. Cette limite est de 20 pour cent pour les menus et de 12 pour cent pour les briquettes. Le fournisseur est donc libre de fournir telle teneur en cendres qui lui convient. Toutefois, l'échelle de variation de prix le conduit à livrer du charbon aussi propre que possible. Actuellement, le charbon moyen a une teneur en cendres située entre 12 pour cent et 13 pour cent.

LABORATOIRES

En dehors des petits laboratoires annexés aux centrales de mélange, le réseau des chemins de fer dispose de 4 laboratoires spécialisés pour l'analyse des combustibles. Trois d'entre eux, installés au cœur même des bassins charbonniers, à Liége, Charleroi et Mons, limitent leurs opérations à la détermination des teneurs en cendres et en eau des combustibles pour locomotives et de la teneur en matières volatiles pour les combustibles spéciaux à divers usages fournis aux chemins de fer.

Le laboratoire central, installé à Schaerbeek (près Bruxelles) est outillé de façon à pouvoir effectuer toutes les analyses, essais et expériences qui intéressent les combustibles.

Ce laboratoire est tout d'abord un laboratoire d'études. Les particularités des provenances des nombreux bassins belges et européens, de leurs mines, de leurs sièges, sont déterminées complètement dans le but de constituer la documentation indispensable à quiconque veut conclure à tout moment les achats les plus avantageux en tenant compte de l'allure des divers marchés européens.

Ce laboratoire étudie aussi les modalités de la combustion dans tous les types de foyer utilisés par les chemins de fer, apprécie leurs rendements, l'influence des divers facteurs relatifs à leurs dimensions, à la dépression, aux systèmes de grilles, etc.

Enfin, il établit, pour le cas particulier du réseau belge, les multiples lois d'influence des teneurs en matières volatiles, en cendres, en eau, de la composition des charbons en dimensions, du pouvoir agglutinant, etc.

Et c'est ainsi que ce laboratoire parviendra à déterminer les conditions optima auxquelles doivent répondre les combustibles que l'on doit acheter ainsi que les mélanges et les régimes de combustion qui doivent être réalisés dans tel type de foyer ou pour telle remorque déterminée.

En dehors de ces travaux, le laboratoire central effectue de nombreuses analyses courantes journalières comme on le verra ci-après.

RÉCEPTIONS

Conditions générales

Les conditions générales sont vérifiées par des analyses effectuées dans le laboratoire central de Schaerbeek sur des wagons provenant des charbonnages, désignés par la Direction des chemins de fer à l'insu des agents réceptionnaires.

Détermination des teneurs en cendres et en eau

Prélèvement des échantillons.—Le nombre de fournisseurs est de quatre-vingt-dix environ, et les fournitures sont presque journalières. Les prélèvements des échantillons sont effectués par une cinquantaine d'agents. Ces réceptionnaires sont des mécaniciens de locomotives détachés périodiquement à ce service. On a estimé qu'il était avantageux de faire effectuer ces opérations par ceux-là mêmes que la qualité des combustibles intéresse le plus directement.

Le prélèvement contradictoire des échantillons s'effectue dans les charbonnages sur les wagons fournis. Il s'opère d'une façon identique dans tout le réseau, suivant des règles qui ont été définies jusque dans leurs moindres détails et dont on exige une application méticuleuse. C'est ainsi que l'outillage: sondes, broyeurs, tamis, etc., est complètement standardisé. Sur le verso du rapport journalier du réceptionnaire sont imprimés une série de rectangles représentant les wagons en plan et sur chacun desquels sont indiqués à l'avance les endroits du wagon où la sonde peut être plongée. Le réceptionnaire a pour obligation d'indiquer sur ces rectangles les N^{os} des wagons qui sont fournis ce jour-là en marquant à la plume, sur chacun d'eux, les endroits où il a plongé sa sonde. Cette prescription a pour objet de permettre un contrôle ultérieur—la sonde ayant laissé sa trace—et de rappeler aussi chaque jour à l'agent réceptionnaire quels sont les endroits bien précis du wagon où l'échantillon doit être prélevé. Le nombre total de coups de sonde doit être de 8 au moins par fourniture journalière, même si celle-ci ne comporte qu'un wagon, avec un minimum de 2 coups de sonde par wagon.

L'ensemble des contenus des sondes est réduit par broyage et tamisage à 4 petits échantillons mis en flacons dont les destinations sont les suivantes: un échantillon reste sur place à la disposition du fournisseur, deux autres sont expédiés dans l'un ou l'autre des

3 laboratoires régionaux, le quatrième est envoyé au laboratoire central.

Extraits des cahiers des charges.—Chacun de ces échantillons sera placé dans un récipient scellé par un double plomb, l'un portant la marque de l'agent de l'Etat, l'autre, celle du délégué du fournisseur.

Préalablement au broyage, l'agent de l'Etat aura prélevé dans le mélange le même nombre d'échantillons frais qui, placés immédiatement dans des flacons à fermeture hermétique et scellés au moyen du double plomb ou du double cachet, auront les destinations qui viennent d'être indiquées pour les échantillons secs.

Ces échantillons doivent servir à déterminer le pourcentage de cendres et d'eau de la fourniture et à faire l'application des pénalités et des primes.

Cette double détermination s'effectuera au laboratoire régional le lendemain du jour de la prise des échantillons.

Le fournisseur ou son délégué sera autorisé à assister à cette opération. Le procès-verbal de l'analyse, que celle-ci ait été ou non contradictoire, parviendra au fournisseur au plus tard le troisième jour qui suit la date de fourniture, les jours fériés légaux n'étant pas comptés. S'il n'en accepte pas les résultats, il devra faire parvenir sa réclamation par lettre recommandée, adressée au fonctionnaire dirigeant le laboratoire régional dont il relève dans un délai de trois jours prenant cours à la date de réception du procès-verbal d'analyse. Une nouvelle analyse sera effectuée au laboratoire régional le lendemain du jour d'envoi de la lettre de réclamation.

Cette seconde analyse ne s'effectuera que si le fournisseur ou son délégué se présente au laboratoire pour y assister.

Les résultats de la seconde analyse seront considérés comme définitifs.

Si le fournisseur ne réclame pas après réception des résultats de la première analyse, ou si la lettre de réclamation n'est pas expédiée dans les délais prévus ci-dessus, il sera censé avoir admis comme exacts les résultats de cette analyse.

Lorsque le taux des cendres impliquera le rebut, les expéditions déjà faites seront considérées comme acceptées, mais l'échelle des pénalités prévue ci-dessus sera appliquée à ces expéditions.

Si un cas de force majeure rendait impossible l'analyse d'une fourniture de combustible, il serait fait application à celle-ci de la moyenne des taux obtenus dans les trois analyses précédentes des fournitures de même catégorie.

Si les résultats d'analyses donnaient des chiffres égaux ou supérieurs à 20 pour cent pendant cinq réceptions consécutives ou pendant plus

du tiers des réceptions du mois, la mise en tas serait prescrite et les analyses ordinaires suspendues. Les tas seraient ensuite analysés, acceptés avec pénalités ou rebutés jusqu'au jour où la mise en tas serait levée et où le régime ordinaire recommencerait.

Si le nombre de résultats égaux ou supérieurs à vingt était inférieur à ces limites, les wagons seraient forcément acceptés puisque leur expédition aurait eu lieu, mais il serait tenu compte de leur teneur en cendres dans l'établissement de la moyenne mensuelle. Quelqu' élevée que soit celle-ci, il lui sera fait application de la règle fixée ci-dessus.

L'importance des tas ne dépassera pas 10 pour cent de la fourniture mensuelle.

Détermination des prix.—Les analyses effectuées tous les jours sur chaque fourniture dans les laboratoires régionaux permettent, par application de l'échelle de variation des prix, de déterminer les 2 coefficients qui, par leur produit, donneront le coefficient final affectant le prix de la fourniture effectuée ce même jour.

Contrôle.—Les opérations de prélèvement des échantillons sont surveillées par un inspecteur qui commande un groupe de réceptionnaires.

Elles sont soumises en outre à un contrôle constant par le moyen suivant. Un certain nombre de wagons sont désignés journellement par la direction des chemins de fer pour être expédiés au laboratoire central qui procède à de nouvelles prises d'échantillons sur ces mêmes wagons, ce qui permet de confronter les résultats obtenus par les analyses de ces échantillons avec deux des échantillons des réceptionnaires. L'organisation établie ne permet aucune relation entre ces réceptionnaires et le laboratoire.

Quant aux analyses des laboratoires régionaux, elles sont confrontées avec celles effectuées sur le 4e échantillon envoyé au laboratoire central.

Appréciation de la valeur de la méthode.—Ce régime fonctionne depuis plusieurs années et a donné entière satisfaction, tant au fournisseur qu'à l'acheteur. Chacun, en effet, y trouve son compte: le premier, parce que ses produits sont payés à leur juste valeur, le second, parce que, tout d'abord, la prime relativement élevée de 2,5 pour cent incite ses fournisseurs à lui livrer des charbons de plus en plus propres et, ensuite, parce que les contrats d'achats qu'il doit passer avec la presque totalité des mines belges pour des variétiés multiples de combustibles sont conclus avec aisance. Un grand nombre de combustibles sont rangés dans une même catégorie pour laquelle seul un prix de base unique est discuté et arrêté

le prix effectivement payé dépendant uniquement des résultats d'analyses effectuées ultérieurement.

On pourrait être tenté de reprocher à ce système le danger ou tout au moins la difficulté qu'il paraît y avoir à faire dépendre de résultats d'analyses un prix de vente de charbons, alors que ces analyses et surtout les prises d'échantillons, ne peuvent prétendre, comme chacun sait, qu'à une approximation assez relative. Mais il faut tenir compte du grand nombre de coups de sonde effectués sur chaque fourniture. Plus de mille coups de sonde sont donnés journellement pour tout le réseau. On comprend aisément que, pour un même charbonnage fournissant du charbon aux chemins de fer d'une façon continue pendant des années, il s'établit sur ces grands nombres une moyenne qui doit représenter pratiquement la teneur moyenne exacte.

On pourrait croire aussi que cette organisation si complète et si méticuleusement réglementée présente des complications, de la lourdeur et, finalement, coûte cher. Au moment où cette méthode nouvelle a été mise en application, le supplément de dépenses qui devait en résulter vis-à-vis des frais que comportait le système ordinaire de réception, a été chiffré exactement. Ce supplément, ramené aux taux actuels des salaires et des matières, est de 0f17 par tonne. Cette somme, d'un ordre de grandeur généralement compris entre 1 et 2 pour mille du la valeur du charbon, est donc insignifiante.

LIST OF EXPERTS

M. Jean Lebacqz, Directeur Général des Mines, 16, rue Guimard, Bruxelles.

M. Herman Capiau, Directeur Général de la Fédération des Associations charbonnières de Belgique, 2, Place Royale, Bruxelles.

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RÉSUMÉ

The Belgian railways use in their locomotives a large proportion of small coals which abound in Belgium, and a small quantity of briquettes and screened coal.

These small coals from Belgian mines show a great variety as regards quality. The Belgian railways are obliged to purchase about two hundred different varieties of coal which have to be distributed to about one hundred points of consumption. Having first determined the chief characteristics which are necessary for a locomotive fuel, the numerous varieties are ordered in proportion to the desired final mixture.

These different fuels have to be mixed very carefully. Owing to the large variety in the quality of the coal, and the numerous points of utilisation, it is impossible to provide each of these points with a mixing plant. The Belgian

railways have, therefore, built four large central stations for mixing and grading, where the coal after being received from the mines is forwarded when blended to the various coaling stations.

In the small depots the coal is discharged by means of either fixed or travelling cranes. In the larger stations overhead discharging platforms or storage hoppers are used, the coal being conveyed from the mixing plant in special trucks.

The Belgian railways have a special agreement with the mines, whereby the price of the coal is governed by a sliding scale based on the ash and moisture content of the coal as sampled when despatched.

The Fuel Control Section of the railways has four laboratories. One central laboratory for general research work and fuel control on arrival, and three regional laboratories situated near the mines for daily analyses in order to determine the price of the fuel as despatched each day.

STORAGE AND HANDLING OF LEMATANG ADMIRALTY COAL

DUTCH EAST INDIAN NATIONAL COMMITTEE

WORLD POWER CONFERENCE

G. J. WALLY

Paper No. D2

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TRANSPORT OF COAL FROM BUKIT ASAM COLLIERIES TO KERTAPATI—QUALITY OF COAL—MECHANICAL HANDLING OF COAL AND LOADING OF SHIPS—COAL EXPORTED AND AVAILABLE MARKETS—CONCLUSION—ZUSAMMENFASSUNG

Kertapati, the terminus of the South Sumatra Railways, is situated on the right-hand side of the river Musi, opposite to Palembang. The terminus of the railway could not be made on the Palembang side of the river owing to the high cost of building a bridge.

The coal from the Bukit Asam Collieries is transported by railway to Kertapati for shipment (distance 165 Km.); the tonnage to be shipped will be 250,000 to 300,000 in this and succeeding years, but with the development of the mine this will increase to about 500,000 tons.

Until 1925, the coal was transported in wooden-sided dumping cars of a net capacity of 10 tons each. There cars were unloaded into the ship from a height of 15 to 20 metres; if there was no ship, they were unloaded on to the ground to be loaded again by hand, when a ship came. This double manipulation was very costly, and the bunkering capacity was limited to 800 tons per day.

In addition, there was much breakage of the coal. The Bukit Asam coal, which is sold under the trade name Lematang Admiralty coal, is a tertiary coal which has been improved by

volcanic action. The quality is very good, about 7,500 to 8,000 calories per kilogram; but owing to the peculiar process by which it is formed, the coal is rather brittle, and the highest quality of 8,500 calories per kilogram and over is too fragile to be sold as lump coal.

At the colliery the coal is screened, and the slack coal is shipped to Java, where it is briquetted in a briquetting plant at Tandjoeng Priok.

To overcome the difficulties, *viz.*, (1) high costs; (2) limited bunkering capacity; (3) handling of brittle coal, a new mechanical coal-handling plant was projected in 1925. This plant has been completed since 1927 and will be in full action in 1928.

At the mine the coal is screened, and by means of a conveyor it is loaded into the railroad car. This car consists of four open buckets placed on a four-wheel truck. Each bucket has a hinged opening, and carries 6 tons, the weight of a loaded car being 38.5 tons. The coal is brought to Kertapati in trains of twenty cars, and if there is no ship the cars are discharged by a crane, which lifts the buckets from the truck.

The buckets are raised level with the top of the coal pile and opened, and in this way the coal is crushed very little. There are three piles of coal, A, B, and C; the outer ones, A and C, 13 metres wide, and the middle one 20 metres; they are all 250 metres long. The storage capacity is 30,000 tons. The cranes, running on tracks alongside the piles, are capable of discharging the cars at the rate of 200 tons an hour. Thus, one train of twenty cars or 480 tons of coal is unloaded in less than an hour and a quarter when working with two cranes.

There are five cranes, of which one is in reserve.

When there is a ship to be coaled the stored coal is loaded into the cars by means of a Brownhoist bucket attached to the crane, the capacity being 3 tons, half of that of a car bucket, the loading capacity thus being 100 tons an hour for one crane.

All the tracks of the cranes are linked by switches, so that it is possible to have all the cranes working on one pile.

The loaded cars are then shunted along the riverside to be dumped in the ship.

Owing to the swampy ground it was too expensive to construct cranes running on bridges for loading the ships, it being necessary to build them on concrete pontoons.

The shunting along the wharf will be done by electric capstans. Before entering the tracks along the wharf the cars are weighed, and the empty cars can be weighed at the other end. Near the scales are capstans to handle the cars.

The pontoons lie between the quay and the mooring posts. They are 20 metres long and 10 metres wide, the depth being 2 metres.

The working radius of the cranes is 16 metres, the height 22 metres above the surface of the water. Ships that draw 6·40 metres can be coaled and the capacity is 150 tons for one crane per hour. All cranes are steam driven.

For the year 1928 there is a guaranteed rate of 1,500 tons per working day of twelve hours.

Until now it has only been possible to load ships of 2,500 tons, as larger ships have difficulty in entering the Musi at low tide, owing to the presence of a bar at the mouth of this river.

In 1927, work was begun to improve this, so that ships which draw 21 ft. can enter daily on high tide, and with 24 ft. draught some days a week, so that ships of 5,000 tons can load and bunker at Kertapati.

Part of the coal is shipped to Javan harbours and Sabang, but an increasing portion is exported. The nearest market is Singapore, at a distance of 300 miles along well-sheltered sea tracts. Moreover, Kertapati is by far the nearest coal exporting harbour to Singapore.

The export to Saigon is also increasing. The distance to the nearest coal markets is given below :—

Kertapati-Penang	... ...	680 miles.
,, Singapore	... ...	300 miles.
,, Bangkok	... ...	1,130 miles.
,, Saigon	... ...	870 miles.
,, Hong Kong	...	1,700 miles.

The coal is of a superior quality, having a low percentage of ash (2 per cent.). The percentage of volatile matter is 30 to 35 per cent., which makes the coal especially good as a steam coal. A small portion of the slack coal is now used in ships having underfeed stokers with moving grates, but the bulk is used in the briquetting plant at Tandjoeng Priok. The briquettes are a high-grade railway fuel, while a selected grade with more than 8,500 calories is used on destroyers.

Conclusion

1. The installation at Kertapati makes it possible to load ships at high speed and with little damage to the coal.
2. The handling being entirely mechanical, the work is practically independent of shortage of labour.
3. With further developments of the Bukit Asam Collieries there will be an increasing tonnage of excellent coal available for export.
4. The natural export market for this coal is Singapore, but for the other harbours in the Far East Kertapati is also favourably situated as regards the distance.

ZUSAMMENFASSUNG

Kertapati ist die Endstation der Süd-Sumatra Eisenbahn. Die Kohlenabfuhr beträgt 250 000–300 000 t jährlich und soll bis auf 500 000 t jährlich steigen. Die Verladung geschieht ausschliesslich mechanisch.

Die Kohlen werden an der Grube in Wagen mit 4 Kübeln von je 6 t Inhalt geladen und in Zügen von 20 Wagen über einen Abstand von 165 km nach Kertapati transportiert. Hier werden die Kübel mittels 5 Landkranen entleert, wobei die Kohlen sehr wenig beschädigt werden. Jeder Kran verwerkt stündlich 200 t. Ist ein Schiff zur Ladung angekommen, so werden die Kübel mittels Greifern von 3 t Inhalt gefüllt, die gefüllten Wagen werden nach dem Kai rangiert und die Kübel durch zwei Pontonkranen in das Schiff entleert (die stündliche Leistung beträgt 150 t je Kran). Alle Kranen werden mit Dampf betrieben.

Für 1928 wurde eine Verladung von 1 500 t täglich garantiert.

Bis heute können Schiffe bis 2 500 Tonnen verladen werden, nach Verbesserung der Flussmündung solche bis 5 000 Tonnen. Die Kohlen sind von vorzüglicher Qualität. Ein stets zunehmender Teil wird nach Singapore und Saigon exportiert. Der grösste Teil geht bis jetzt nach Sabang und Java-Hafen. Die Feinkohle wird in Tandjoeng-Priok brikettiert.

STORAGE, HANDLING AND TRANSPORT OF OMBILIN COAL AT EMMAHAVEN

DUTCH EAST INDIAN NATIONAL COMMITTEE
WORLD POWER CONFERENCE

D. ALLEMAND

Paper No. D3

CONTENTS

CONSUMPTION OF OMBILIN COAL—METHODS OF STORAGE—TYPES OF WAGONS USED—METHODS OF BUNKERING USED FOR SHIPS HAVING LARGE HATCHES ACCESSIBLE FROM ABOVE, SHIPS HAVING LARGE HATCHES ACCESSIBLE FROM THE SIDES, SHIPS HAVING SMALL HATCHES IN THE GALLERIES—TRANSPORT OF COAL BY AERIAL ROPE-WAY TO THE CEMENT WORKS—ZUSAMMENFASSUNG

Introduction

The Ombilin coalfields are situated at 55 Km. distance from Emmahaven, on the West Coast of Sumatra, behind the Barissan Mountains, in a region without appreciable possibility of selling the coal. The annual coal production amounts to about 500,000 metric tons on an average. Apart from the small quantity of coal directly supplied to the State Railway, almost the entire production has to be transported to the harbour at Emmahaven. To this end a railway is provided having a length of 156 Km., the track gauge being 1 m. Part of the track is of the toothed rack type.

Consumption of Ombilin coal may be classified as follows, in percentages of the total production.

10 per cent. is consumed by the State Railway,
20 per cent. is taken by ships as bunker coal,
60 per cent. is taken by ships as cargo coal and transported to other harbours all over the Archipelago.
10 per cent. is supplied to the cement works at Padang.

The long railway track on the one hand, the irregularity of intervals between the arrivals of ships at Emmahaven on the other hand,

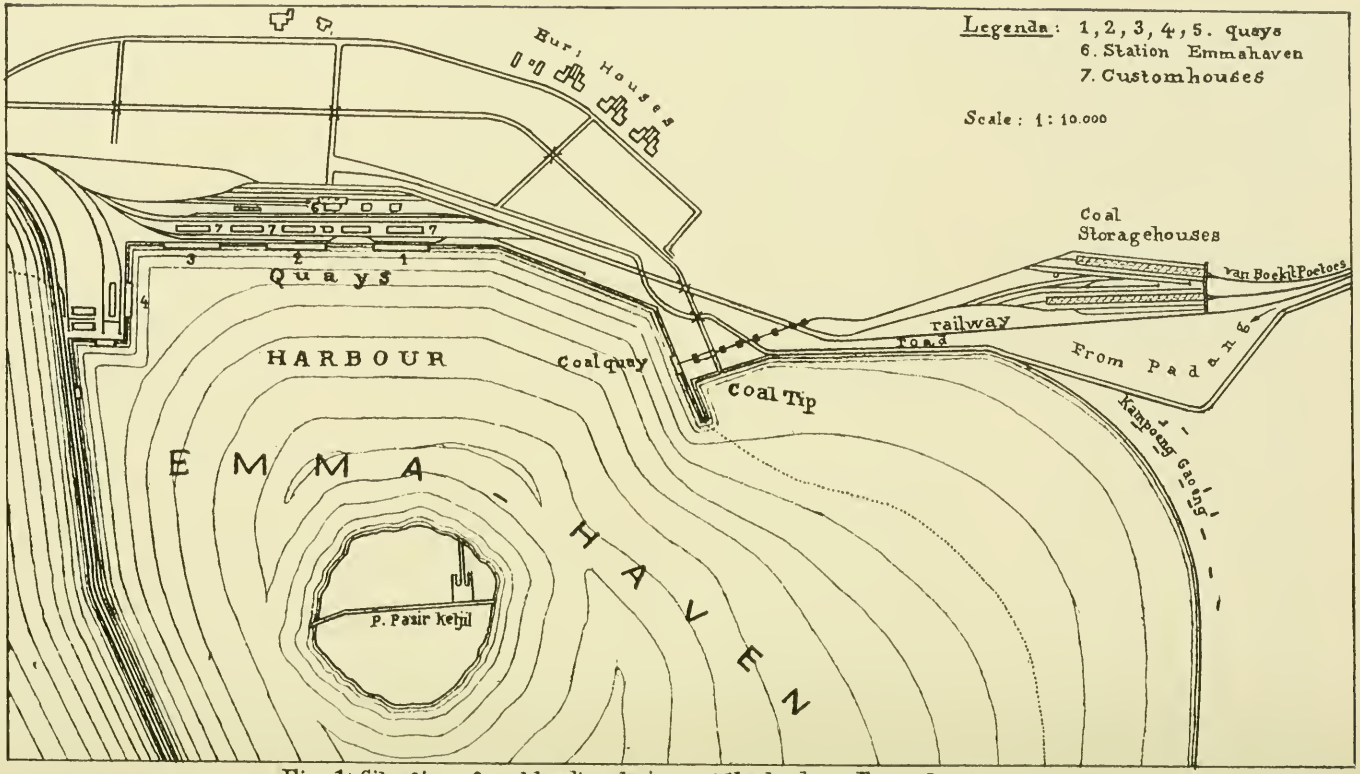

Fig. 1: Situation of coal loading devices at the harbour Emmahaven.

necessitate storage houses of large capacity near the harbour. To prevent crushing or pounding the coal is stored in roofed buildings or coal sheds at Emmahaven.

Coal Storage Houses

Fig. 1 is a general view of these storage houses showing their arrangement and situation. They are situated in a small valley, and their exact place has been chosen so as to minimise the total length of inclined planes to be constructed for bringing in the coal. To prevent fire from the spontaneous combustion of this sort of coal the height of the piles should not exceed 5 to 6 m. Therefore, an oblong shape has been given to the storage houses in order to reduce the number of tracks required. At Emmahaven there are two storage houses, their total length being 175 m. and 200 m. respectively. All coal passes through these storage houses before being loaded into vessels.

Particulars of Construction. Both buildings are of the same type and subdivided by cross-walls into thirty and thirty-five compartments respectively, as is shown in Fig. 2, representing a sectional

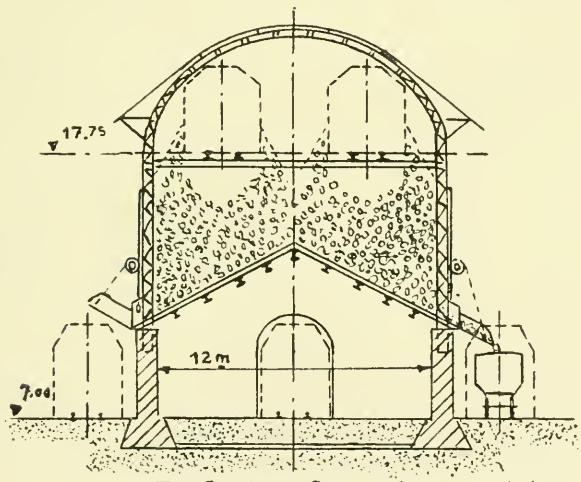

Fig 2: Coal Storagehouse. 1:400

view. These cross-walls serve as a means of support for the two entering tracks, which extend over the whole length of the buildings. The floor of the storage house is inclined at an angle of 30° and drops from the middle towards both longitudinal walls. It is composed of wooden planks supported by steel beams. The

longitudinal walls extend vertically upwards to the level of the entering rails and have their lower part provided with openings, each compartment having two. These openings are adapted to hoppers, which may be swung upwards by means of hand-operated reels so as to close the openings when in their upper position. The roof and the walls are composed of steel beams and covered by corrugated galvanised sheet iron.

The advantage of dividing the storage houses into compartments is that the diverse sorts of sized coal can be stored separately.

The storage house is supported by two longitudinal walls of masonry, the height of which is such as to make the hoppers mentioned above project just above the special cars used with the loading device. Each compartment has on the level of the outgoing rails one opening in the longitudinal walls and one in the cross-walls. The size of the latter is such as to permit normal cars to pass through over a special track.

Coal is supplied to the storage house directly from the adjacent terminal station, Boekit-Poetoes. Trains composed of six cars—the cars coming from Sawah-Loento—are pushed upward on a short incline by a locomotive, which is allowed as far as the rear part of the storage house. When the cars have reached the proper spot, the side doors are opened and the coal is discharged on both sides of the track simultaneously. Empty cars are returned to Boekit-Poetoes by the locomotive.

Operation. It needs only five men to handle the filled cars in the storage houses, including two men running the locomotive, and the others on the cars for operating the brake and the doors.

Should there be insufficient room for the coal, it is piled on the track by a gang of ten to fifty men. For this purpose one of the front compartments is discharged into special flat cars which are returned *via* Emmahaven Station and Boekit-Poetoes to the upper track of the storage house, where they are discharged by hand, the coal being piled up over the full compartments at the back. By this measure the front compartments always remain empty, thus continually providing sufficient room for the immediate discharge of the cars, which can be afterwards returned to the mine at Sawah-Loento, without delay.

Capacity. The storage houses have a storage capacity of 5,000 and 8,000 tons, respectively, when filled in the ordinary way to the level of the entering track. Their total capacity may be increased from 13,000 to 15,000 tons by handling as described.

The actual shipping conditions still necessitate the use of this tedious measure five to ten times a year.

A further increase of storage capacity to 20,000 tons may be realised by utilisation of the room under the compartments. In this case the first compartment is discharged on the ground, or in flat cars, and the coal shovelled under the storage house. To remove this coal provision is made of a third track running underneath the building, and flat cars are used. It has not been necessary to recur to this extreme measure during the past four years.

The coal which is to be taken from the storage house is discharged in cars of a particular design, which, in order to be filled, are shunted alongside the compartments. The loaded cars are moved alongside the building by a shunting locomotive drawing four cars, passing the switch shown in the drawing, to one of the scales. The cars, after being weighed individually, are transferred to one of the shunt-tracks. Another shunting engine serves to pull the cars from the shunting tracks past the scales to the coal-tip or to the crane. The arrangement of tracks and scales is shown in Fig. 1.

Operation. There are two workmen for operating the hoppers, two at the scales and two to four for manipulating the switches.

The weighing scales. Their weighing capacity is 20 tons. To weigh the car, the bridge between the rails is raised by operating a screw spindle till the car is lifted from the rails. The weight of the car is automatically recorded by impression on a card.

The Wagons

Transportation of coal to the storage house, and from it, is realised by cars of five different types, each car being provided with a hand brake.

The coal is loaded at the mine in saddle-bottom wagons, having a capacity of 12 tons and 24 tons, respectively. The cars are made of steel and may be covered by corrugated sheet iron roofs. One type (E cars) has one, another type (K cars) has two receptacles mounted on the frame, each having a capacity of 12 tons. The E cars are four-wheeled, the K cars have eight wheels. The inclination of the bottom, from the middle to the sides, is 30°. The lower portions of the side walls act as swinging doors, being hinged at the top and controlled by a system of screw spindles and levers attached to the bottom end of the doors.

To feed the coal-tip cars are employed which discharge at the bottom; their capacity being 10 tons. They have one wooden

receptacle. The door consists of two steel plates, which may be independently operated from the platform by means of screw spindles. The maximum width of the door opening is slightly less than the track gauge.

The cars used to supply the coal cranes have removable iron receptacles discharging through bottom openings. Their constructional features may be compared to those of a grab. Two of these receptacles are supported by a steel truck, but they are freely movable on it. Each receptacle has a capacity of 6 tons.

Bunkering by manual labour. The flat cars already mentioned are of the common type, having side doors, hinged at the lower end. The receptacle is made of wood, and rigidly connected to a steel truck.

The shunting locomotives. The locomotives are of two types, having a tractive force at the draw-hook of 2,200 Kg. and 4,300 Kg., respectively.

The Loading Devices

Ships calling at Emmahaven may be classified as follows, with regard to the accessibility of their bunkers.

1. The bunkers have large hatches accessible from above: colliers, proas, and some cargo-boats of European companies (express cargo steamers).
2. The bunkers have large hatches accessible from the sides: passenger steamers bound for Europe.
3. The bunkers have small hatches in the galleries: all steamers of the Royal Mail Steam Packet Co., which keeps up communications in the Malay Archipelago.

Formerly coaling was exclusively done by coolies, but about the year 1900 the coal tip and in 1915 both cranes were erected. The tip is used with vessels of the first class, when the height of the bunker gates does not exceed 10 m. above sea-level. The cranes are used with vessels of both first and second class. Those belonging to the third class still require the use of manual labour.

Fig. 1 is a plan showing the general outlay of the harbour and the situation of the loading devices. The tip is somewhat isolated on the coal-wharf because of the coal-dust formed when in use. The cranes can be used for bunkering vessels moored at the main quays. There are three main quays situated side by side. Vessels belonging to the third class are moored at Quay 4 and operated upon by coolies carrying coal in baskets.

THE COAL TIP

A single track is provided for coal supply to this loading device. From the storage house the track mounts along the slope of a hill, the maximum inclination being 18 per cent. It crosses the railway-tracks and the main road to Emmahaven overhead upon a steel framed viaduct, having a length of 110 m. in five spans, and prolonged in a bridge of 80 m. length, the end portion of which projects well above the quay. There are two tracks on the bridge which are made to join by means of two switches, one at the beginning of the bridge, the other at about 20 m. from its outer end. The length of the shunt is sufficient to have four cars placed on it. The height of the track is 14 m. above sea-level. The bridge is level, but the viaduct has an upward grade of 25 per cent. Both the bridge and the viaduct are planked. The planks between the rails at the extreme part of the track may be removed over a distance of about 10 m. Thereby one of the four adjacent openings is cleared, each of them corresponding to one of four parallel chutes supported at an angle of 30°. All chutes have their lower extremity situated on a vertical plane passing through the end of the bridge. There is a further chute having an opening which may be adapted to any of the preceding chutes by means of a hand-operated reel. This chute is a telescopic one, in order to permit an exact adjustment of the opening above the bunker holes or hatchways of the ship. The variations of the water level due to tidal effects being only 1·70 m., and the height of the tip being 14 m., the latter may be used with all vessels loading cargo coal.

Running the plant. Trains leaving the storage house are made up of four cars. The cars are pushed by a locomotive which immediately takes back to the storage house the four empty cars previously shifted. The filled cars are not coupled together; but the empty ones, of course, are. The initial velocity imparted to the filled cars by the locomotive is such as to make the first one run as far as the dumping point. The other cars are stopped before reaching the switch by operating the brake. The first car, when emptied, is shifted to the other track by twelve coolies, the next full car being now brought to the dumping point by a further gang of twelve coolies.

Operating. The locomotive is driven by two men; four men operate the brakes, each of them remaining with his car. There are two gangs of twelve coolies occupied in moving the cars on the bridge, two coolies manipulating the car doors (one at either side),

two coolies cleaning the empty cars, two coolies cleaning up the tipping stage on the bridge, two for handling the reels, one foreman and four more coolies for successively relieving the others. Thus the full loading capacity of the bridge is maintained from 6 o'clock in the morning till 6 o'clock at night.

Capacity. The maximum quantity of coal which the tip is able to load into the vessel is 270 tons hourly.

When bunkering coaling boats, the coal tip is also partially made use of, provided the coaling-scuttle is large enough and within reach of the hopper. This kind of boat has generally two large scuttles, one being at starboard, the other at port. Ordinarily the tip can only be used with one of these scuttles, as it is necessary for coolies to throw coal through the other one. For this purpose, full coal cars are supplied from the storage house and halted under the tip, the coal being taken then in baskets and carried on board by coolies.

The most characteristic feature of the tip, the most important of the coal conveying devices to be found at Emmahaven, as the total weight of coal taken on to ships from it is 300,000 tons yearly, is (with the exception of the locomotive mentioned before) the complete absence of engines.

The Coal Cranes

As is shown in the general plan (Fig. 1) of the plant, two coal cranes are provided which are used for bunkering ships moored on Quay 1, 2 and 3. Constructional details are shown in the photograph (Fig. 3). These cranes are of the gantry type and motor driven. They travel on a track alongside the quays. The rails being laid on both sides of the custom-house sheds, it follows that these buildings are contained within the opening confined by the bridge and its legs in order to permit the crane to travel beyond them. The crane proper can move over the bridge, and has a range equal to the entire length of the bridge; it may be swung through a full circle about its axis. The maximum working radius of the boom is 8 m.

The gantry cranes are entirely power driven. Three-phase alternating current is supplied at 440 V., to induction motors of the wound rotor type with brushes and slip rings. The controllers and resistances of the crane proper are located within the crane hut. The hoist comprises two double drums, one containing both hoisting cables, the other carrying the auxiliary ropes. Both drums are

driven by one motor transmitting its movement by a system of bevel gears. The auxiliary drum may be uncoupled by a clutch in order to stop it independently of the hoisting drum and to halt it by a brake.

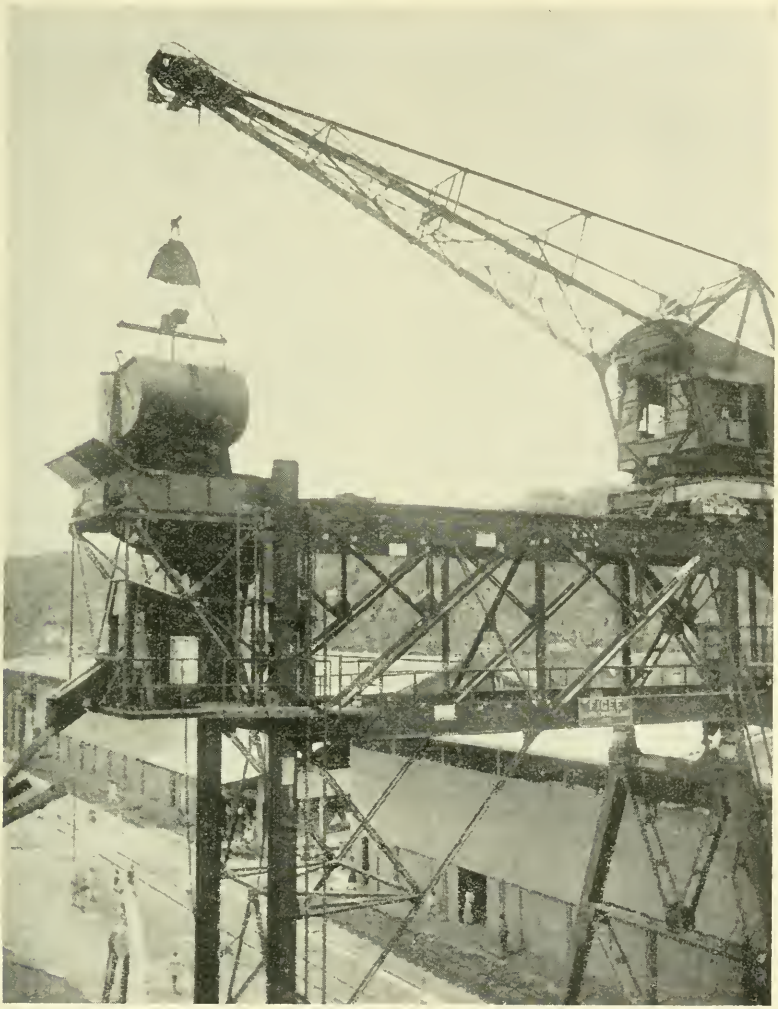

Fig. 3. The Coal Cranes at Emmahaven. Details from coal hopper and bucket.

The bridge is propelled by means of an electric motor which, combined with the controller and resistance, is located at the middle

of the bridge. The movement of this motor is transmitted to one of the wheels in both legs by spindles and bevel gears.

The seaward end of the bridge projects for a length of about 10 m., and carries a coal hopper at its extremity. The coal hopper is protected by a casing (see photograph, Fig. 3). The casing and the hopper together with the chute are one unit and carried by two screws, so as to permit the adjustment of their position vertically. The chute is extensible owing to a telescopic arrangement. The interior of the casing contains the apparatus for controlling the hopper and the chute; the former being motor-driven, the latter operated by hand.

Current is taken from a ground cable by plug contacts at every 50 m. of the entire length of the quays, and supplied to the apparatus within the casing by means of a flexible cable terminating in a plug to be inserted in one of said plug contacts and wound upon a reel carried by the station side leg of the bridge.

Operation. Trains, made up of ten loaded cars driven by a locomotive, leave the storage house at the west side of the quay to enter one of the three railway tracks, and are stopped under the gantry crane between the station and the customs-house sheds. Each receptacle on the cars is then in turn lifted by the crane so as to clear the sheds, traversed until it is over the bunkers, lowered and then discharged by manipulation of the auxiliary ropes.

Should the ship have side hatches, the coal is dropped into the hopper at the extremity of the crane bridge and, after passing through the chute, falls into the bunker.

Operation. The personnel required to attend both cranes consists of one overseer and eight men, *i.e.* for each crane one crane-attendant, one man at the hopper, two men for connecting and disconnecting the hooks to the receptacles. There is one shunting engine and another locomotive to convey the cars to the storage house and back.

Capacity. Each crane has a loading capacity of 60 tons hourly. As a rule both cranes are used at the same time in loading one boat. In comparison to one single crane of double capacity, there is the advantage of an improvement in the continuity of coal supply to the ship and that of smaller variations of power consumption. The lifting capacity of each crane is 8 tons, and the weight of the contents of a receptacle is 6 tons.

Bunkering by Handpower

Ships in class three are exclusively supplied by coolies carrying on board the coal-filled baskets. To fill the baskets coal is taken from the flat cars already mentioned.

Coal Furnished to the Cement Works

This coal is supplied from the terminal station Boekit-Poetoes. This station is a terminus both for coal supply and of the aerial rope-way owned by the cement works. Cars destined for these works are discharged on the ground after being shifted on to an auxiliary track next to the rope-way. The carriages of the rope-way are loaded by the coolies of the cement works.

ZUSAMMENFASSUNG

Die jährliche Gesamtförderung der Ombilin-Minen von Sawah-Loento beträgt im Durchschnitt 500 000 t, wovon die Staatsbahn und andere lokale Industrien ungefähr 100 000 t verbrauchen, während der Rest regelmässig von Emmahaven aus verschifft wird, und zwar ungefähr 100 000 t in der Form von Bunkerkohlen und 300 000 t als Ladekohlen.

Die Verbindung zwischen Emmahaven und Sawah-Loento wird vermittelt durch die Staatsbahn, eine Schmalspurbahn von 156 km Länge.

Hieraus ergab sich die Notwendigkeit, in Emmahaven sowohl Kohlenspeicher zu errichten, als auch moderne Verladeeinrichtungen zu besitzen.

Die Kohlenspeicher: Zwei nebeneinander liegende Speicher von 12 m Breite und 175 bezw. 200 m Länge enthalten 35 bezw. 40 Silos mit sattelförmigen Böden. Die Zwischenwände reichen bis unter die zwei Zufuhrgleise, denen sie damit zugleich als Unterstützung dienen. Die beladenen Kohlenwaggons, die sattelförmige Böden haben, werden mit einer Lokomotive oben auf die Silos gefahren und entleeren sich durch einfaches Öffnen der Seitenklappen. Zum Entleeren der Speicher stehen ebenfalls zwei Gleise zur Verfügung, die (10 m tiefer als die Anfuhrgleise) an den Längswänden der Speicher entlang führen. Das Entleeren in die Kohlenwaggons geschieht durch Herunterziehen einer an die Siloklappen anschliessenden Kohlenrutsche.

In die Abfuhrgleise sind zwei Brückenwagen für je 20 t Gewicht eingebaut.

Das Fassungsvermögen der Speicher beträgt normal 13 000 t, kann aber um 3 000 t vergrössert werden durch Aufstapeln der Kohlen von Hand.

Man verfügt heute in Emmahaven über folgende Ladeeinrichtungen:

Eine Verladebrücke, die zur Bekohlung derjenigen Schiffe dient, deren Bunkeröffnung tief liegt und von oben her zugänglich ist (Kohlenladschiffe und Prauen).

Zwei Portalkranen, die herangezogen werden, wenn diese Öffnungen hoch auf der obersten Brücke oder in den Seitenwänden liegen (Europäische Fracht- und Passagierdampfer). Zur Bekohlung der Schiffe, deren Bunkeröffnungen in den Dienstgängen liegen, ist man noch immer auf Handarbeit angewiesen.

Die Verladebrücke: Von den Kohlenspeichern aus führt eine einspurige Bahn, zunächst einem Hügel entlang, zu der 80 m langen, freitragenden Verladebrücke, deren äusseres Ende genau über der Kademauer und 14 m

über dem Wasserspiegel liegt. Auf der Brücke befindet sich eine Ausweichstelle mit Raum für vier Waggons. Am Brückenende sind vier parallel unter einander angeordnete Kohlenrutschen eingebaut. Beim Beladen von Schiffen wird eine fünfte Rinne jeweils an diejenige Rutsche angeschlossen, die ein Gleiten der Kohlen bei geringstem Gefälle ermöglicht. Die Anfuhr der Kohlen geschieht in Zügen von je vier Waggons, die durch eine Lokomotive bis zur Ausweichstelle auf der Brücke gestossen werden; von hier aus bis zum Falltrichter und zurück zur Ausweichstelle geschieht die weitere Bewegung von Hand. Die Kohlenwagen werden durch Öffnen von zwei Klappen, die sich zwischen den Rädern befinden, entleert. Die Leistung mit einer Lokomotive und 42 Kulis beträgt normalerweise 3 200 t in 12 Stunden.

Die Kohlenkranen: Die Portalkranen können die ganze Länge der Handelskaden 1, 2 und 3 bestreichen. Auf den Portalkranen ist je ein Drehkran montiert. Die Kohlenzufuhr geschieht hier mittelst Wagens, auf dem zwei lose eiserne Behälter in der Form von Greifern wie bei Baggermaschinen und mit je 6 t Inhalt stehen.

Die Drehkranen bringen die Kohlenbehälter bis über die Bunkeröffnungen, wenn diese von oben her zugänglich sind, und entleeren sie in diesem Falle direkt in die Bunker. Bei Schiffen mit seitlichen Bunkeröffnungen fallen die Kohlen aus den Behältern erst in einen Fülltrichter am Kopfende des Portals und von da durch eine Rutsche, die auf diese Öffnungen eingestellt werden kann, in die Bunker.

Man arbeitet immer mit beiden Kranen zugleich und bedient dabei nur ein einziges Schiff. Ihre Leistungsfähigkeit beträgt in diesem Falle 120 t je Stunde.

THE STORAGE AND HANDLING OF SOLID FUELS BY THE USER

TECHNICAL COMMITTEE, FUEL CONFERENCE, 1928

R. K. STOCKWELL

Paper No. D4

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FACTORS AFFECTING THE INSTALLATION OF THE PLANT—SPONTANEOUS COMBUSTION—HANDLING PLANT—SHIP UNLOADING—RAILWAY WAGON UNLOADING — FEEDING — ELEVATING — CONVEYING — ASH DISPOSAL—STORAGE AND RECLAMATION

ZUSAMMENFASSUNG

Factors Affecting the Installation

Before deciding on any installation it should be clear that, by using that type, the cost will be less than with any other system. This cost is the sum of the three items, maintenance cost, operating cost, and interest and depreciation on investment. It is the sum of the three that is all-important, and to obtain the lowest sum total it is advisable to consider the three costs in their order of importance.

It is common practice to put capital or first cost as the leading factor, but, while this may be true reasoning in some instances, in the majority of cases maintenance cost is really the governing factor. The worst fault that any system can have is that of high maintenance cost, because reliability and dependability in operation are involved. The factor of maintenance is often the result of a natural desire to keep first cost at its lowest possible figure, but this may bring in its train not only the known and anticipated wear and tear expenditures, but also indirect and incalculable losses due to breakdowns, loss of time, and upsetting of routine and programme. The only way to avoid such conditions arising is to examine the proposed system on its general reputation, extent

of use, and satisfactory operation over a period of time by other users, and to be assured that the system is one of the manufacturer's staple products in which he has had much experience and of which he intends to continue the manufacture; and not that his interest is only in the present contract for machinery and will vanish after the plant is paid for.

The operating cost is simply the labour cost per ton handled, plus the cost of power, oil, etc. This cost may often be reduced proportionately by increasing the capacity per hour without a corresponding increase in either the interest or labour charges. When considering the design for a new plant the first cost, and consequent interest cost, as previously mentioned, appear to be the principal factors. When operating a plant, however, one's worries as to costs are not about the interest cost but about repair and upkeep costs and reliability of the installation. The lowest first cost seldom results in the lowest operating costs. The interest and labour costs can be calculated before the plant is built, but the maintenance and breakdown expenses, due to what is misnamed cheap plant, cannot.

The justifiable expenditure for a fuel-handling plant depends on the amount of coal to be handled and on the other individual circumstances. Other expenses may completely overshadow the cost of fuel handling, making such costs of installation and operation of less importance. Guarantees against interruption of operation, by delayed arrival of fuel, by labour troubles, or other causes, may justify considerable investment in fuel-handling and storage plant. Each problem is different and must be decided on its merits. Large users are nearly always warranted in the installation of elaborate handling plant which would not be justified for smaller users. Even in the smallest plants, however, the handling of the fuel should be carefully considered. In addition to any direct reduction in operating expenses the use of conveying machinery induces cleanliness and neatness about the plant which results in better care of all machinery and, in plants where there is little room, the installation of a suitable conveying system often increases the storage capacity.

The amount of fuel storage desirable depends on the regularity of the supply, the importance of avoidance of a shut-down due to interruption of supply, purchasing ahead due to seasonal price fluctuations, the expected future growth of the plant, and on local conditions. It is well to look as far ahead as possible to future

requirements, and design the plant in such a manner that it may be extended in the future without difficulty.

The storage should be as close as possible to the point of use and connected with this in such a manner that the fuel is normally sent direct to the furnace bunkers but can be easily directed to, and reclaimed from, storage. The different storage systems in use are parts of various handling systems, and the application of each type of machine to both handling and storage will be described under the names of the different machines. Before considering means of storage it is well to consider spontaneous combustion. This is an ever-present danger with coal storage and therefore coal should be stored so as to prevent it, and the storage system used should be of a type capable of use in easily and rapidly overcoming a fire.

Spontaneous Combustion

It is generally accepted that the main cause of spontaneous combustion of coal is the direct action of the atmospheric oxygen on the coal itself. The principal part played by pyrites is to break up the coal into fines by slow oxidation of the pyrites. This disintegration is aided by the alternate wetting and drying of coal in storage. The fine coal oxidises more quickly and at the same time prevents free circulation of air carrying off the heat as fast as it is generated by oxidation. Complete safety for stored coal lies either in sufficient ventilation or else in the hermetic sealing of the coal from all access of oxygen, either in free circulation of air or in no air at all. To secure free circulation of air all fines must be removed and only lump coal stored. This is not economical and is seldom practicable. Elimination of air altogether means underwater storage, which is not always possible or desirable. Rolling and closely packing the pile is nearly as effective as underwater storage. Making a homogeneous pile, by preventing segregation of sizes, retards oxidation due to lack of air.

The time of greatest danger from spontaneous combustion is from six weeks to three months after storing. The heating generally begins at a depth of about 7 ft. from the surface, at a point deep enough to prevent escape of the heat as generated and still near enough to the surface to maintain the supply of oxygen. In a homogeneous or packed pile this point is much nearer the surface and moves about, due to changes in surface temperature, thus preventing firing. When storing an unfamiliar bituminous

coal the temperature at various points in the pile should be watched carefully, by means of pipes sunk into the pile, and at 130°F. warning should be taken. At 150 or 160° the coal should be used, or moved and spread out to cool. At 180° smoking will begin and firing is about to start. With an unfamiliar coal or one known to heat easily, the storage system should be one with which a hot spot in the pile can be dug out and spread easily. Coal from a hot spot should be separated from the rest of the pile and spread out on the ground away from anything likely to be endangered if it should break into flames. Such hot spots should be handled carefully, and a good supply of water should be at hand to quench flames that might start. Water is of little use after firing has started, except to quench surface flames. Wetting a burning coal pile often forms a wall of coke around the burning part, preventing the water reaching the heart of the fire and allowing the fire to break out again later. A deluge of water that reaches a warm spot will prevent further heating.

The storage ground should be dry, level, and free from drainage from any source. Care should be taken that pieces of wood, oily waste, or other combustible material, are not mixed with the coal in storage. Avoid storing coal near external sources of heat, even though the heat transmitted be moderate, and do not store against buildings. Avoid admission of air to the interior of the pile through drains beneath the pile and around foreign objects, such as poles, posts, gantry legs, girders, beams, irregular brickwork, or through porous bottoms, such as coarse cinders. Do not place different kinds of coal in the same pile, nor place fine coal adjacent to lump coal, as fires tend to start on the borders between the two. Pile the coal homogeneously so that all sizes are well mixed together. Avoid coning, rolling down a side of a pile, or other causes of segregation and stratification, since an open stratum of lumps permits air to reach and oxidise the fine coal, and the stratum of fine coal does not permit the heated air to pass off rapidly enough to keep the temperature below the point of combustion. The height of the pile depends on the nature of the coal and the method of storing. Piles 5 ft. deep have taken fire and many piles 50 ft. deep have not. If stored without care the piles should not be over 12 or 15 ft. deep. If stored according to the above rules, coal is fairly safe 20 to 25 ft. deep, but, if also rolled and packed into storage the coal is practically as safe as in underwater storage and the pile may be of any height.

When coal is stored under shelter, or inside buildings, surface ventilation should be secured to facilitate the escape of gas by the circulation of the atmosphere. When a fire is discovered in a storage pile the only satisfactory method of extinguishing it is to dig it out, remove the coal to another section of the yard, and spread it out to cool. It is always advisable to make the storage in such a way that any part of the pile may be moved promptly if necessary.

The heating value of coal seems to be decreased little by storage, possibly from an average of 1 per cent. up to a maximum of 3 per cent., during the first year in an open storage. No deterioration whatever is experienced with coal stored under water, and little in a packed pile, while there is apparently an actual gain in heating value in coal stored under salt water. Stored coal loses a little of its coking qualities and of its value for making gas, and in firing it needs to be spread in thinner layers over the firebox.

So many types of equipment have been developed for the handling of coal and coke, and their functions so overlap and aid each other, that it is difficult to choose the most suitable for a given problem without a wide experience in their uses and limitations. The detailed designs of all these mechanisms have been often described and may be found in technical books and manufacturers' catalogues. These details are constantly being improved and developed by competing manufacturers, and the user can generally rely on their being of the latest and most suitable design for the type of machine in question when supplied by a manufacturer with long experience in making that particular machine.

The user is faced with the problems of unloading his fuel, transporting and elevating it to his bunkers, and storing and reclaiming. Occasionally, with a small plant and suitable conditions, one machine will perform all these duties, but generally a combination of several machines is necessary.

Ship Unloading

Where water-borne coal is available it is usually cheaper than rail-borne coal, and consequently efforts are made to locate power stations, especially the larger ones, on navigable waterways. The locations of the buildings on the site should be decided with principal reference to the coal-handling plant to be used.

In British practice the coal is grabbed from ships and barges either by cranes or transporters. The capacity of any of these

grabbing machines can only be calculated exactly when all conditions are known and coal will be certain to be within reach of the grab.

The maximum capacity is possible at high tide with full cargo. At other heights of the tide, and as the coal is lowered in the ship, the hoisting distance is increased and capacity is decreased, and, during the final cleaning up of the cargo there is no coal available for the grab until trimmers have worked it within reach. The unloading plant designer can give a real guarantee only for the breaking-down capacity. For that he has exact data. He may make a close approximation to the total cargo unloading capacity if a certain ship and the number of trimmers to be used are specified, but for a general guarantee that any machine will have a certain average capacity when unloading ships in general he can only make a guess. A safe guess is that, unless the ship is of unusual type, with very small hatches, or 'tween decks, the average capacity will be 50 per cent. of the breaking-down capacity for ships under 2,000 tons; 60 per cent. for ships of 2,000 to 5,000 tons; and 70 per cent. for larger ships.

Locomotive Crane. This is a very efficient machine for ship unloading, when its operations are confined to hoisting a grab bucket and delivering its coal to some other machine for transportation, reserving its locomotive powers for locating itself advantageously to the hatch or for moving from one hatch to another. Its flexibility and usefulness in shifting railway wagons, travelling to stock out and reclaim coal, and other odd jobs about the plant, often give a wrong impression that detracts from its great value as a ship unloading machine. For unloading from ocean-going colliers, at breaking-down capacities up to 150 tons per hour, it seems to have the advantage in cost, flexibility, and economy. For larger units there is a difference of opinion, and some prefer the transporter.

In Great Britain the units of largest capacity for unloading coal from ships are cranes as exemplified on the Thames in many units of 250 to 300 tons per hour capacity. Users claim that the crane is best able to cover the hatch area and saves considerable cargo trimming by being able to swing the grab back under the hatch combing. In the larger sizes the costs of transporter unloaders and cranes are about the same, and the two types are about equally used in Great Britain for high capacities, for while cranes are more used for coal unloading, transporters are more used for ore

unloading. This healthy condition of technical competition has resulted in the development in Great Britain of excellent types of fast, high-capacity, grabbing cranes not made abroad, while still keeping up to the mark on transporter design.

The operating cabin of a ship unloading crane should be elevated to a position from which the operator can have an unobstructed view of his grab at all times. The quite different uses of locomotive cranes for storage and reclaiming are mentioned later.

Transporter. There are various types of grabbing machines called transporters, but they all have the one feature in common, that, in addition to their grabbing and hoisting actions, the grab full of coal is transported back to some discharging point. When used most efficiently for ship unloading they generally have a very short run back and discharge the coal to another machine for disposal. In this work they are in direct competition with locomotive cranes as previously mentioned. The choice between cranes and transporters depends on the manner in which they fit into the general design of the complete coal handling and storage plant. The somewhat simpler mechanism of the transporter, its ability to hoist higher and deliver higher on shore, and the ease in spotting the grab in the hatchway with the operator directly overhead in a man trolley, should be compared with the advantages of the crane.

On the Continent the man-trolley type of transporter is in general use for ship unloading. In America it is used less, except on the great lakes, where it has been developed into the great ore bridges and where the Hulett unloader is also used with the special type of lake ships. It has not been found practicable to use the Hulett unloader on ocean-going vessels with small hatches and often with 'tween decks. The rope-operated type of transporter is used somewhat in Great Britain; less on the Continent, where they like to have the operator always over his grab; but has been greatly developed in America, where they use very high rope speeds and obtain great capacities.

The bridge transporter, of the man-trolley type, is often used for the combined purpose of ship unloading, storing, and reclaiming coal. The grab is run back to discharge coal to storage pile, or to wagons, and may later reclaim from storage to ship, barge, or wagons. Sometimes the back leg of the transporter runs on the boiler-house wall, or bunker, and the grab can discharge to storage

outside, or to the bunkers inside. This scheme is not often used as the span of the bridge is limited, resulting in small storage, and there is no chance of extension. However, for a small station, supplying a small town where the chance of extension is slight and where coal can be received in barges, a small bridge transporter of this type is often useful. At first sight it looks like an ideal installation, but there are several disadvantages. A long bridge transporter is very expensive, due to supporting the loaded grab and trolley on a long run over the storage pile, the ship unloading capacity is greatly decreased, due to the long run back of the grab, and the length of the storage pile can be no greater than the length of the dock. The capacity question is sometimes solved by mounting a belt conveyor on the transporter to reduce the service of the grab. In this case the grab confines its work to ship unloading, discharging the coal immediately to the conveyor, which discharges to storage or to another conveyor leading to the fuel bunkers. With such a conveyor transporter the grab trolley, or crane on top of the transporter bridge, is moved to any spot in the span and remains stationary while its grab reclaims from the store beneath and discharges to the conveyor on the transporter. This conveyor carries the coal across the transporter bridge to the fixed conveyor on the ground, paralleling the transporter run, which carries the coal to the bunkers.

Telpher. The telpher, generally of the man-trolley monorail type, is widely used for small plants to unload from barges, discharge to storage or bunkers, and reclaim from storage to bunkers. This is similar to the work done by the bridge transporter, but instead of being movable along the dock, the telpher is on a fixed structure, which necessitates moving the ship. For small plants, where future extension need not be considered, and quickness of discharge of the ship or barge is not of great importance, a telpher installation does very well. The storage is small, as the line of the grab run is fixed; also, if the storage is on the ground, the telpher can only recover about half the amount stored, the remainder having to be handled within reach of the grab. A telpher is likely to be misused by having it do too much running back over the storage, which reduces its unloading capacity. A large telpher that will handle 200 tons per hour when travelling back 40 ft. will only handle 50 tons per hour if it travels back 400 ft. As a telpher stores in a straight line it cones and segregates the coal.

Steeple Tower. This is a special type of rope-operated transporter much used on the North Atlantic coast of America for unloading ships. It is made either fixed or to travel along the dock. The grab is controlled by a double-drum winch, the ropes working over a rope-operated trolley, running on a horizontal boom projecting over the ship. A separate drum controls the movement of the trolley, with one man controlling the entire operation. The steeple tower confines its work to grabbing and hoisting, at very high speeds and high capacities, discharging to a belt conveyor on the dock. The operation is simple and the speed astonishing, the grabs often not coming to rest when discharging. The structures for these towers were made of timber for many years but now are also made of steel. Both steam and electric towers are in use.

Mast and Gaff. Another machine much used in America, for unloading ships, when the cost of a steeple tower would be too great, is the mast and gaff rig. Its use is confined to grabbing, hoisting, and discharging to the dock or to an elevated hopper. It uses a double drum winch, either steam or electric. The mast swings through a fixed arc and cannot be luffed. Being a fixed device the vessel must be moved.

Stiff Leg Derrick. This is one of the simplest devices for unloading ships. For small stations a derrick is often very useful, not only for ship unloading but for making and reclaiming storage as well. For equal capacities, however, its cost is greater than a mast and gaff, and also greater than a locomotive crane, which is much superior. Unlike the mast and gaff its boom may be luffed, but like the latter, it is a fixed device and the stiff legs often occupy valuable space.

Railway Wagon Unloading

Track Hoppers. Where coal is received in bottom-dump railway wagons the track hopper is perhaps the best method of unloading for plants in Great Britain, or warm countries, where severe winter conditions that sometimes make this method so difficult by freezing the coal solid in the wagons do not exist. With the 20-ton bottom dump wagons in use in the North of England a very high discharging capacity is secured by handling the trains across a track hopper with a locomotive, as a wagon may be dumped clean in about half a minute with free running coal, and within two minutes with washed coal and slack. Without the

locomotive, and without a capstan or other means of haulage, with only a slight down grade to assist the moving of the wagons by hand over the track hopper, discharging capacities up to 500 tons per hour have been maintained with these wagons by the efforts of two labourers.

For most efficient unloading the track hopper should not be used for storage but only as a quickly self-cleaning transfer chute. Its containing capacity depends on the amount of coal to be handled. For high throughputs it may hold less than a wagon load, so that the wagon may dump clean and get away quickly. For smaller throughputs it may hold less than a wagon load, and the wagon must wait until it is empty. The removal of the coal from the track hopper to the elevating and conveying system should be by means of a positive, power-operated feeder, with capacity control regulation. Many types of such feeders are discussed later.

Wagon Tipplers. The end tippler has been much used in Great Britain at small and moderate sized plants for unloading the eight and ten-ton railway wagons made with one end hinged to drop down. One end of the wagon is lifted up to slide the coal out of the other end into a track hopper. The older tipplers had a hydraulic cylinder beneath the track, which lifted the end of the wagon under one axle. The disadvantage of this type was that the end buffers of the wagon struck the track and prevented further tipping when the angle of tip was only about 50 degrees. The rough wood bottoms of the wagons retarded the coal at this angle and much barring and scraping was necessary. Continued lifting, after the buffers had struck the track, often resulted in derailment of the wagon. The newer tipplers have overcome these troubles. The wagon runs on to rails supported by a steel frame which is raised and tipped by the hydraulic cylinder, or an electric motor, and any desired angle of tip may be reached with the buffers clear of the track.

One disadvantage still remaining for any plant, except the smallest, is that the hinged doors are in only one end of the railway wagons, and so, with only one tippler installed, there must be a turntable to turn about those wagons that arrive facing the wrong way. By installing two tipplers, one on each end of the track hopper, this is taken care of, but such an installation is complicated, expensive, needs a deep pit, and the newer stations are generally installing wagon dumpers.

Wagon Dumpers. These turn the railway wagon nearly upside down and discharge the coal to a hopper, from which it is removed by a suitable feeder at any desired capacity to the elevating and conveying system.

Two types of dumpers are in general use, one lifting the wagon in a cradle, the other revolving it in a cage. Local conditions have much to do with choosing the type to be used. If the railway track is considerably above the ground level the revolving dumper is generally used. If the railway track is on ground level the deeper pit needed by the revolving type is often objectionable. While the revolving type uses smaller motors it discharges the coal deeper below ground level, from which point it must again be elevated, and the extra power required for this about equals the extra power required for the lifting type dumper. Both types are thoroughly reliable and their use is rapidly increasing.

A third type, or rather a modification of the lifting cradle dumper, which lifts the wagon to any desired height, to the level of the bunkers, for instance, before dumping it, is a most interesting development. There are occasions when this machine is most useful, to deal with some peculiar condition, such as preventing coal or coke breakage, but on the whole, like most machines designed to do two or more different things at once, its elevating work, for which a much cheaper machine would suffice, greatly reduces its dumping capacity.

Feeding

A feeder is a vital unit in most coal or coke-handling plants. It regulates the discharge of the material and feeds it to the conveying system in such a manner and at the required capacity to work the conveyors to their highest efficiency by keeping them fully loaded but never overloaded. It smooths out the change from the intermittent receipt of material by grab or wagon to the continuous flow required in conveying. A good feeder is a labour saver.

Gates. The many types of gates are all used as feeders, when the material is free running and will flow by gravity, or as cut-offs, to stop the flow altogether for some reason. The choice of the type of gate depends on the location and its use. A simple slide gate, worked by hand-wheel, rack, and pinion, is much used when an occasional cut-off is required. An under-cut arc gate is very useful for occasional discharges from bins to wagons, skips, or

other intermittent conveyors. When the material is too large and quantity too great for an arc gate, even when power-operated, an up-thrusting slide gate, hydraulically or electrically operated, is often used. Roller slide gates, lifting chute gates, double arc cut-off gates, and many others, have their different uses when their choice is governed by experience.

Reciprocating Feeders. These have been standardised in several types, jigging or shaking feeders which jerk the material along on a plate or pan, plunger feeders which push the material, and displacement pan feeders which are used for lumpy materials and greater capacities. All types are much used, as they are simple and not expensive and they are easily adjustable to give close regulation to the material fed. While these feeders are sometimes used for very high capacities it is not usual to design them for more than 200 tons of coal per hour.

Roll Feeders. These are not so much feeders as they are retarders. They control the flow of freely flowing materials. They are of little use on wet or sticky materials unless made of great size so that the material rests on them in the bin. For gentle retardation of materials, such as coke, from a quenching hearth or bin, to a belt conveyor, or free running coal, they are very good. The rotary paddle type is a good feeder for approximately measuring fine material.

Belt Feeders. The use of these overlaps that of the reciprocating feeders, but they are generally used for higher capacities. They have been standardised for capacities from 50 to 2,000 tons of coal per hour. In the smaller capacities, where they overlap, they are generally more expensive than reciprocating feeders but are capable of much closer measurement and regulation of the material, and so are much used for exact mixing and blending of small coals. They are preferable to reciprocating feeders on an elevated structure or in a building because of freedom from vibration. A belt feeder takes a little more power than an equivalent reciprocating feeder, and its operating and maintenance costs are about the same.

A belt feeder cannot turn sharply upward from beneath a hopper and consequently headroom, or depth of pit, can be saved, when of importance, by using an apron or pan feeder. A belt conveyor can only turn upward on a curve that is near the catenary taken by the belt when it is empty on the curve but loaded at its lower end. This natural curve has a radius, which is easily calculated,

of from 120 ft. to 450 ft., according to the load and the belt pull. The penalty of using a smaller curve than the calculated catenary is injury to the belt, by its rising against the skirtboards in case of a feeder, or leaving the idlers and so not running straight in case of a conveyor.

Apron or Pan Feeders. These are steel conveyors and are made in several styles for different uses. They all, however, have aprons, pans, or plates, for carrying material, supported by chains running over sprocket wheels. They are much used for heavy ore and stone work, taking product from power shovels and feeding such large material to crushers, in which cases they are of heavy construction and the chains are supported on rollers the full length. For fuel handling, however, they do the same work as belt feeders but are more expensive. Their advantage over belt feeders is that they can turn sharply and carry the material up a steeper incline. Power, operating, and maintenance costs, when handling coal, are about the same as those of belt feeders, but when handling coke or other abrasive materials the maintenance cost of chain conveyors is higher, also, breakdowns take longer to repair.

Screw or Spiral Conveyor. This is used for conveying horizontally fine dry non-abrasive materials, and is excellent for pulverised coal and cement, as, besides conveying them, it can be made to press out much entrained air. For lumpy or wet sticky coal it is troublesome, and for coke the wear is rapid and maintenance cost excessive.

Other Feeders. There are numbers of other types of feeders for special uses, but they are not used frequently for fuel handling. The revolving table feeder is an excellent measuring device and good for feeding fine materials and is much used in washing plants. It takes very little headroom but does not work well on large lumpy material. Many types of feeders have been developed to screen material as it is being fed, but these have never become popular and have a very limited use.

Elevating

Before considering the uses and limitations of conveyors in general, many types of which may also be used to elevate material, it will be convenient to discuss those machines used only, or principally, as elevators. Two lifting types of unloaders have been mentioned, the grab hoist and the high lift wagon dumper.

While both are useful for special conditions, their elevating functions reduce their unloading capacities, which are usually of greater importance.

Bucket Elevators. These are of two types, the chain-and-bucket, where the buckets are attached to one or two chains running over sprockets, and the belt-and-bucket, where the buckets are attached to canvas or rubber belts. Either type may be vertical or inclined and have continuous or non-continuous buckets. They are used to elevate any material that will not adhere to the bucket. The length and capacity of elevators are limited by the strength of the chains or belts. Belt-and-bucket elevators are well adapted to handling abrasive materials such as coke, which would produce excessive wear on chains, and are also used for larger capacities, and are not liable to sudden unexpected breakdowns such as a weak or worn link in a chain elevator sometimes causes. Both types are standardised in several styles and are much used for elevating coal from track hoppers to the bunker level for distribution by a horizontal conveyor.

Gravity Bucket Conveyor. This chain-and-bucket machine, which elevates vertically and also conveys horizontally, is very useful. It is much used in power stations and gas works to elevate coal from the track hopper and distribute to any part of the bunker, and also, sometimes, then to run underneath the furnace on its return journey and bring out the ashes. Its use for handling ashes in power stations is declining, the latest practice being to do so only for a certain moderate-sized plant, below which size the amount of ashes is too small to warrant placing so little of such an abrasive material in an expensive machine with numerous wearing parts, and above which size the amount of coal to be handled is too large to endanger the supply by maintenance repairs to chains worn by ashes dust. Its most efficient use is to save ground space by vertical elevation, combined with a short horizontal run to distribute over bunkers, with a lift under 100 ft. and a capacity between 25 and 100 tons per hour. For smaller or larger capacities, or where more ground space is available, cheaper and more efficient installations can be made with other machines.

Skip Hoists. These are much used to elevate material intermittently to discharge directly into an overhead bin or bunker. For ashes disposal at power stations they are often used to raise the ashes, in the same hand-truck in which they are collected, or after

being dumped into a permanent skip bucket, to the elevated loading bin. In such cases the hoisting, dumping, and returning, are consecutively automatic upon being started. Such installations are very useful for small locomotive coaling stations, power stations, or gas works, to raise coal from beneath the track hopper to an overhead bin. For labour saving, or for larger capacities, skip hoists are made completely automatic. They then have an automatic measuring feeder to fill the skip bucket. This feeder is the crux of the design and of efficient automatic operation. Several British makers have had valuable experience from which they have developed good designs.

Skip hoists are especially useful for handling lumpy material, such as large coal, or abrasive material, such as coke, and breakage can be greatly reduced by their use. Their principal limitation is that, as their discharge is intermittent, it is difficult to distribute from them with a continuous conveyor. This necessitates a receiving hopper, with a discharging feeder, installed at a great height, which is usually too expensive. For simple elevation of lumpy material, without distribution at the top, an automatic skip hoist is the most efficient installation, for the least investment, for capacities between 60 and 150 tons per hour.

Pneumatic Conveyors. This system of suction-handling material through pipes is much used in the grain trade, and many attempts have been made to adapt it to coal handling. It works very well, for capacities up to about 20 tons per hour, when handling coal that is as nearly like grain as possible, that is, when the coal is small, dry and clean. It seems such a simple method of unloading, elevating, and distributing, all with the one machine, that it is tempting to designers of small plants in which the amount of coal to be handled is so small that the first cost of the installation is of paramount importance. However, it is noteworthy that the installations at power stations have generally been replaced or supplemented by other types of handling plant. The reasons generally given are high power cost, difficulties experienced with the air-filtering apparatus, and trouble handling wet, sticky coal.

Conveying

Conveyors may be divided conveniently into continuous conveyors and intermittent conveyors. The continuous conveyors may be divided again into those which push or pull their load, and those which actually carry the material. One disadvantage of the

types of conveyors that push or pull material along in a trough is that friction consumes power and causes wear. The carrier type is usually more economical in operation. The belt conveyor has come to be considered the most efficient of the carrier types, but the advantages of the principal types used in handling fuel will be discussed.

One of the most interesting developments in coal conveying has not received the consideration it deserves. The conveying of coal by mixing it with water and pumping it through a pipe was worked out and perfected at the Hammersmith power station in 1914, where it is still working. It is described in detail in the 1922 edition of Zimmer. It is simple, cheap, and effective under certain conditions, and should not be forgotten.

Screw or Spiral Conveyor. As mentioned under "Feeders," these machines have a limited use handling certain fine materials. Although a very inefficient pusher conveyor there are occasions when they may be used to advantage distributing over short bunkers in small plants, where the coal is always small, and never wet or sticky, at capacities up to 30 tons per hour, and when low first cost is all-important. They occupy little headroom and distribute without attendance.

Scraper Conveyors. These are made in different styles called push plate, drag link, U link, flight conveyors, etc., and are all chain conveyors with attachments for pushing or dragging material along a trough. They are not efficient conveyors in power consumption and wear, yet, under certain conditions they may perform work economically. This is especially true where the first cost of the apparatus is of greatest importance. Improved types are much used to distribute coal over bunkers in small boiler houses and gas works. They are generally used in lengths under 150 ft. and for capacities below 70 tons per hour. Their advantages are cheapness, low headroom, automatic distribution along their length without attendance, and ability to convey up a steep inclination. The disadvantages are high power and maintenance costs, small capacity and inability to handle large coal. Sometimes used to make small storage piles, they dump the coal in a line which cones and segregates the sizes. The same machine is seldom used for reclaiming.

Apron and Pan Conveyors. These chain conveyors of the continuous carrying type have been described as feeders, which is their principal use in handling coal. Their advantages have always

been ruggedness and high capacity. They are much used for conveying large pieces of heavy ore, hot materials, or for taking the shock as a feeder and then discharging gently to a cheaper but less rugged carrier of equally high capacity. Being all steel, with many wearing parts, they do not stand up well to the handling of abrasive materials, such as coke. As they can only discharge at their head ends they are not used to distribute materials, or for storing, but are very useful to collect materials from various feed points and deliver to another conveyor. Their ability to carry up a steep incline is mentioned again as very useful.

Tipping Tray Conveyor. This is another chain conveyor of the continuous carrying type, somewhat cheaper and less rugged than apron and pan conveyors of equal capacity but more useful for coal carrying, as they can distribute material, discharging throughout their lengths at any fixed or movable point or points. They can carry up a steep incline and handle hot materials. They are frequently used in gas works to distribute coal and coke to charge and furnace hoppers of vertical retorts, and are very useful for such distribution to separated hoppers.

Electrical Weigh Larry. This is much used in moderate-sized power stations to distribute coal from a bin at one end of the boiler room to the stoker hoppers. Its use eliminates overhead bunkers and allows the construction of a skylight over the boiler room. It automatically weighs and records the weight of the coal delivered to each stoker. A bucket elevator or skip hoist is generally used to raise the coal to the elevated bin. This system is simple, inexpensive, and economical. It is preferable to the travelling weighing hopper, used under overhead bunkers, on account of greater simplicity and lower cost, although not having quite as much capacity.

Steel Belt Conveyors. These are much used for handling wood, in logs, planks, and timbers, as well as hog fuel, in the Scandinavian countries, and for handling bricks and wet, sticky clay. They have been little used for coal and coke handling. They have obvious advantages, cheapness of installation, small headroom occupied, simplicity of construction, and discharge at any point in their lengths by scraping ploughs. Their principal disadvantage for bulk materials is that the conveying medium is a narrow flat band with small capacity.

Rope and Disc Conveyor. An endless rope with discs or buttons

attached at intervals for pulling articles along a trough is much used in timber countries for conveying wood. It is a cheap, easily constructed, and efficient machine for pieces of wood. It has been used as a cheap temporary method of making a coal storage pile, but its efficiency is very low with coal, its conveying capacity small, and the coal is dropped in a line so that it cones and segregates.

Shaking Pan Conveyors. These have been little used by the users of fuel although much used by the producers of fuel. They are much used at collieries both under and above ground, though being used above ground generally for screening. One type, the reciprocating pan, has been described as a feeder, but in that use the pan is inclined too steeply to be used as a conveyor. It is probable that the wet, sticky coal, so much used by power stations and gas works, has limited its use in those fields.

Belt Conveyors. These were in use 130 years ago as continuously carrying conveyors with flat flexible leather belting. About 50 years ago the canvas and rubber power transmission belts of that time were used to make flat belt conveyors to carry grain and other light materials. About 36 years ago Robins developed the rubber and canvas conveying belt for the carrying of heavy lumpy materials, and also the practical method of troughing a belt to give it great carrying capacity. Its first extensive use was carrying the heavy abrasive mineral ores of South Africa, and now, although it is widely used to carry all sorts of bulk materials, even hot coke immediately after quenching, the majority of the world's belt conveyors are probably carrying coal.

The use of the belt conveyor has become so general and widespread that it is in danger of abuse. It looks such a simple machine that it is difficult to realise that years of costly experience and development were necessary to bring it to its present state. Each time an installation is made without that experience as a background some of the expensive mistakes of the past are repeated.

Belt conveyors for coal and coke should be of strong, rigid construction and of the troughed type. The light construction and flat belts used to carry grain and other light materials should be avoided. All details of design should have relation to increasing the belt life. The design of the mechanical parts and supports of a belt conveyor greatly affects the life of the belt. When belt

replacement costs are high, due to short belt life, it is generally the fault of the installation and seldom the fault of good modern conveyor belting.

All the wear of the material carried should be taken by the rubber cover of the belt, and the canvas body should be considered only for tension and flexibility. Experience has shown that for each width of belt, and each material to be carried, there is a maximum belt thickness, above which the belt is too stiff to trough, and will spill material and not run straight. There is likewise a minimum thickness below which the belt is too flexible and will spill material. Between these extremes the number of canvas plies and the weight of canvas to be used are matters of calculation of the horse-power pull and not of opinion. The longer a conveyor is the better it is for belt wear, as the wear takes place only at the feeding point.

Clearances should be ample to prevent the running belt rubbing against anything. Side guides should be avoided. In most cases proper design of pulleys and idlers will keep the belt running straight. The diameters of all pulleys around which the belt bends should be large enough to avoid extreme stresses in the belt. There should always be a dirt-tight floor or deck between the carrying and return belts to prevent pieces of material dropping on the return belt and being pinched between it and the tail pulley. The designs of chutes, the proper width and speed of belt for different materials, and many other points are important, but are matters of experience. The starting up of new belt conveyors should only be done by a mechanic well experienced in belt conveyors. The first month is the critical time, but after this is passed belt conveyor operation is a labourer's job.

The principal advantages of belt conveyors are their simplicity, low first cost, and high efficiency. Their high capacity is a large factor in their high efficiency. For small capacities they are often not the most economical, especially if the small capacity must be continually maintained. For such cases a belt conveyor of higher capacity, working a shorter period each day, is often more economical, if applicable. Between 30 and 50 tons of coal per hour, transporting up to a distance of about 200 ft., a belt conveyor is well worth consideration. For higher capacities, up to 2,000 tons per hour, and increasing the distance with the capacity, up to a maximum of about 3,000 ft., it seldom has a competitor. They are often used to elevate materials up an

incline, being a very efficient elevator when the capacity to be handled is sufficient and there is room available. The maximum advisable incline for lumpy coal is 18 degrees. They are made reversible, movable, swivelling, raising and lowering, luffing like a boom, portable, to make storage and reclaim from store, for self-unloading ships, with travelling stackers, etc. Unless mounted on a travelling bridge they store coal in a straight line which cones and segregates it. They distribute over bunkers or storage piles either by a travelling tripper or by using what is known as a reversible shuttle conveyor, which is generally preferable when conditions allow its use.

The equable climate of Great Britain is kind to belt conveyors, but British engineers have every extreme to contend with in the various parts of the Empire. The icy winters and snow of North America affect belts little, but increase the power consumption due to thickened lubricating grease. In such inclement climates it is advisable to enclose belt conveyors in galleries as a protection to the men, so they will not neglect the machinery. In tropical countries a cover over the belt is desirable to shield it from brilliant hot sunshine.

Aerial Ropeway. This is a very useful conveyor for cases that have not the high capacity or short haul so suitable to belt conveyors, or the long distance requiring railway haulage. When the distance to be transported in feet is from ten to sixty times the number of tons to be handled per hour, it is well to consider the aerial ropeway, up to a capacity of about 150 tons per hour. The economical distance is greater in mountainous country where a railway would be too costly.

Other Conveyors. The use of the cable railway is declining in fuel handling and few developments or improvements have been made in it for years. The rope cableway is little used now for coal handling. Railway trestle, or gantry, storage of coal is declining on account of first cost and as the gantry legs in the coal seem to cause fires by conducting air into the pile. Portable conveyors, or elevators, are useful for very small storage plants such as retail coal dealers' yards or the smallest of power stations or gas works.

Ash Disposal

When selecting the fuel-handling plant a decision must be made

on the question of handling the residue with the same machinery. Separate systems are always provided in large plants where the amount of fuel used is enough to occupy the handling machinery during the day shift. In small power stations where the coal may be handled in a few hours, the same conveying system is often used to handle coal and ashes alternately. However, where the abrasive action of the ashes would shorten the life and increase the maintenance costs of the coal conveyor, a separate system for each is best. In gas works, as the amount of coke produced is a considerable percentage of the coal used, it is seldom that one carrier is used for both materials, even in the smallest of the latest plants.

In small and moderate sized power stations ashes are often handled intermittently by hand-pushed cars, or skips, to an automatic skip hoist. In the largest plants immersed drag chain conveyors are often used, but the wear is great and maintenance high. Belt conveyors are excellent for ashes, but only after they have been quenched. The hydraulic sluicing system is developing rapidly, the continuous system has many disadvantages, but the intermittent system with ash storage hoppers under the stokers and sluicing once a shift with high pressure nozzles is simple and economical.

Storage and Reclamation

Railway Storage. For large seasonal storage piles, where the coal is kept in storage for a year or more, railway storage is usually the most economical means. It may also be used to advantage for small working storages where first cost of an installation is all-important and operating costs not so important. Some large gas works unload wagons by locomotive cranes, or by hand, to the pile, and move the track sideways on the coal as the pile is made. Coal is piled from 12 to 20 ft. deep by this method with little danger of firing in Great Britain, where the climate allows storage in summer at moderate temperatures that tend to prevent heating. The packing of the coal in the pile, by the weight of the trains, also retards heating. One large gas works on the Thames, using this method, watches the temperature of the pile carefully and deluges a warm spot with water until it is cool again. The difficulty of digging out a heated spot is the great objection to this method of storing.

When the wagons are unloaded by cranes the grab loads of coal

may be placed in layers in the pile to avoid segregation of sizes, but with unloading by hand-shovelling this is not done and there is more danger. In India, where hand-unloading is done by coolies with baskets, segregation of sizes in the pile may be avoided, but the high tropical temperatures keep the safe height of the piles down to 6 or 8 ft.

When an initial ramp is not available and wagons must be unloaded on the ground level, locomotive cranes are generally used, and the coal is unloaded into long piles between parallel tracks. The coal should never be discharged from the grab at a height and allowed to drop, roll, and segregate. What is called "spread piling" should be adopted, the grab being opened close to the surface of the pile each time, its load being deposited as a whole in one spot, and different spots chosen each time to keep the surface as level as possible while building the pile.

If the pile be rolled by a heavy roller or a heavy tractor after each layer or two of coal has been added, the pile may be safely built to any size and height. A heavy caterpillar tractor, drawing an ordinary road scraper or drag, may be used to spread the coal from where it has been placed by the grab, and make a tightly-packed homogeneous pile. It is not economical to scrape coal back very far from the track by this method, and if the distance to be scraped back is over 75 ft. a cable drag scraper, which has the same stratifying and packing action, should be considered.

When coal or coke is to be stored from railway wagons that have been loaded at the works, a special self-unloading wagon is sometimes used to advantage. This, called a "coal taxi" or "coke taxi," has a hopper holding 40 tons of coal, or 20 tons of coke, with an electrically-operated unloading and stacking belt conveyor attached. It is hauled about and operated by a small oil-driven locomotive mounting an electric generator. The use of the taxi has definite limitations in capacity and length of haul, but when the job is within its limitations it is very economical. It is, of course, self-unloading on its return journey when reclaiming.

Hand reclaiming from railway storage to wagons is declining, even where cheap coolie labour gives the lowest cost, because of its slowness and uncertainty. Grabbing by locomotive cranes has been the usual method of reclaiming, and where the cranes are also used for unloading and storing it is the most economical. The use of power shovels for reclaiming is increasing and lower cost with less breakage is claimed. Portable conveyors may be

considered as aids to manual handling. When used with good shovellers they greatly improve on manual handling capacities and costs per ton, distributing from wagons, stacking, and re-filling wagons, for very small storage plants. They are, however, almost useless with labourers who are not used to shovels, such as the eastern coolies, who are used to baskets. A motor tractor with a lifting shovel attachment is a new development that may be of use to small plants for packing coal into store and later digging it out.

Conveyor Storage. A storage made by an overhead conveyor is generally a small, or moderate sized, working pile, and seldom a large seasonal deposit. On this account liberties may sometimes be taken with the heating danger, and the coning and segregation of sizes are chanced. Reclaiming by a conveyor in a tunnel beneath the pile is much used. Some small plants have one gravity bucket elevator-conveyor to take coal from the track hopper, elevate it, and deposit it into store, distribute over bunkers, and also reclaim from store. This is an expensive type of storage plant, however, and usually a simpler machine is used for the horizontal conveying. Belt conveyors are much used for tunnel reclaiming, and the tunnel gates may be sealed air-tight for long storage periods. This method is useful for high capacities, but the tunnels are generally too expensive in first cost for any but large plants. The principal disadvantage with tunnel reclaiming is that, under a flat-bottomed pile, it only reclaims about half of the storage by gravity, and the remainder must be handled to the tunnel.

The reclaiming conveyor is often placed on the ground and is fed by a power shovel or locomotive crane grabbing from the pile. The storing belt conveyor can be made reversible and the same conveyor used for reclaiming; a travelling hopper, with a feeder, on the conveyor, being fed by the grab or shovel. Sometimes the conveyor from track hopper to bunkers is used to distribute into a storage pile between the two, a crane passing the coal back to increase the store or reclaiming to the same conveyor again. A great variety of arrangements may be made with conveyors and cranes.

Transporter Storage. This has been the type generally used for the elaborate and expensive installations for large plants. Its advantages are high storing and reclaiming capacities, a large storage capacity, and ability to dig from any part of the storage at short notice. Coals may be stored separately and reclaimed as

desired, and a hot spot may be dug out quickly. The largest working storages at plants are now made with various combinations of belt conveyors and transporters. The travelling transporter is fed by a conveyor, and reclaims to it again as it works at any point in the length of the pile. The transporter discharges to the pile by conveyor and reclaims by grab to a conveyor. Such a pile is often 200 ft. wide at its base, 32 ft. high, and any length desired. The longest pile served by one belt conveyor alongside, at the present time, is 1,400 ft. long. By using a tractor to roll and pack the pile as it is made, the fire danger can be practically eliminated and the grab kept at useful work.

This type of storage is well worth consideration for a working storage of 20,000 tons or more. For 50,000 tons or more it is the most economical, and once it is installed it may be extended to double or treble its original capacity with little extra expense. For high-capacity storing and reclaiming, 200 tons per hour and over, combined with large storage capacity, it is generally the best. Its great competitor now is the cable drag scraper system which should always be considered at the same time.

Cable Drag Scraper Storage. This device is becoming very popular for storing and reclaiming coal on the ground. As usually installed, the coal is delivered by conveyor or elevator to an initial pile, from which the scraper spreads it to cover the storage area. The scraper can dig from any part of the storage and deliver to a hopper, from which other devices elevate and transport the coal to the bunkers. It also can reclaim to a hopper which loads railway wagons by gravity.

These systems have been built for capacities from 40 tons per hour up to 500 tons, based on an average haul of 100 ft. The storage area can be of odd shape and need not be level. The coal is stored homogeneously in thin layers and the entire area is covered. Only one operator is necessary. Coal is reclaimed from any part as fast and as easily as it is stored. Fires seldom occur, due to the way the coal is piled and packed, but they can easily and rapidly be dug out of any part of the pile, and the hot coal spread out to cool, with the operator at a distance. The system is very mobile, and will fit any other storage area to which it may be moved. The first cost is low, as is also maintenance, which consists in replacing worn cable. Labour cost is very low, the operation being simple.

The three disadvantages are coal breakage, cable wear, and

shifting the tail blocks, but these are not very serious. The system is generally used for power stations or gas works where coal breakage matters little. There is difference of opinion as to breakage; however, some locomotive coaling stations use it and the operators maintain that the scraper can be handled to avoid breakage. The rope is pulled back and forth over the storage pile and with abrasive materials the rope wear is high. With coal, however, which is graphitic in nature, the rope wear is about the same as on a locomotive crane. Moving the tail blocks is simple in the smaller systems, but for a large system it is best to use a moving car, on a track around the outside of the storage, to carry the tail blocks, instead of using post anchorages.

Everything is simple and straightforward except the scraper itself, which is the heart of the system, and although it is a little thing, it can make, or render useless, the whole installation. The shape of the scraper, and the manner of its attachment to the hauling cable, are all-important. In operation, after digging out its load, the scraper slides along over the top of the pile. A peculiar shape and method of slinging achieve this and are the result of expensive experience. One should be cautious of untried types of scrapers.

Underwater Storage. Railway storage in pits filled with water, reclaiming by locomotive crane, transporter storage, and cable drag scraper, are all used for underwater storage. The disadvantages with all are the deterioration of grabs or scrapers working in water. The system in general works under great difficulties in cold climates with much freezing weather, but in the tropics it is at its best. The coal grabbed from the depths is sometimes piled on the coal above water to drain and dry before using. It is interesting to note that at the great Government coal storage plants in the Panama Canal zone, which have been using both ground and underwater storage systems for years, the underwater systems have lately been given up. This indicates that open ground storage of coal is considered safe under tropical conditions.

ZUSAMMENFASSUNG

Es wird ein allgemeiner Überblick über das weite Gebiet der Förder- und Verladeeinrichtungen für feste Brennstoffe, wie sie im ganzen britischen Reich verwendet werden, gegeben. Die wirtschaftliche Seite dieser Anlagen

wird besprochen. Die wichtigsten Verwendungsweisen und -grenzen der verschiedenen Systeme werden behandelt und wirtschaftliche Vergleiche gezogen für das Löschen von Schiffen, Entladen von Bahnwagen, Zubringen, Heben, Fördern und Lagern, wie auch für die Behandlung von Asche. Beim Auswählen des geeignetsten Systems zu beachtende Gesichtspunkte werden mit Bezug auf Anschaffungs-, Betriebs- und Unterhaltskosten entwickelt. Die Verhütung der Selbstentzündung gelagerter Kohlen wird ausführlich besprochen und verschiedene Lagerungssysteme beschrieben.

GENERAL REPORT ON SECTION D

STORAGE AND HANDLING OF SOLID FUELS BY THE USER

DR. W. R. CHAPMAN

1 There are four papers presented to this section of the Conference, entitled :—

D1 "Methods of Control, Preparation, Handling, and Storage of Coals by the National Railways of Belgium" (Belgium), by H. Chenu.

D2 "Storage and Handling of Lematang Admiralty Coal" (Dutch East Indies), by G. J. Wally.

D3 "Storage and Handling and Transport of Ombilin Coal at Emmahaven" (Dutch East Indies), by D. Allemand.

D4 "The Storage and Handling of Solid Fuels by the User" (Great Britain), by R. K. Stockwell.

The subject matter dealt with in these papers may be divided under the following headings :—

(*a*) Storage.
(*b*) Loading into storage or into ships, etc.
(*c*) Unloading.
(*d*) Handling by the user.
(*e*) Blending arrangements.
(*f*) General.

2 Chenu's paper (D1) describes the coal-mixing plant used by the Belgian State Railways to ensure the use of a uniform quality of fuel, and the arrangements made for fuelling locomotives at stations of various sizes. It deals at some length with the chemical control necessary for the success of the mixing plant.

3 The coaling arrangements at two East Indian ports, Kertapati and Emmahaven, are described by Wally and Allemand (D2 and 3).

4 Stockwell's paper (D4) describes the plant used in handling coal for a variety of purposes. It summarises the relative advantages and disadvantages of different methods, and might well form the basis of a more extensive work on the subject.

(*a*) *Storage*

5 The general rules to be observed in storing coal are described in D4 (p. 2), the methods of avoiding and combating spontaneous combustion being considered.

(*b*) *Loading and Storage Plant*

6 D4 summarises the various methods and forms of plant used for storage and reclamation (p. 511). The methods of storing coal are :—

1. Railway storage, most suitable for large quantities and long periods.
2. Conveyor storage, most suitable for small working piles in which liberties may be taken with the heating danger.
3. Transporter storage, for elaborate installations requiring high storage and reclaiming capacities.
4. Cable drag conveyor, for general ground storage.
5. Storage under water.

7 The special coal storage houses at Emmahaven are described in D3 (p. 481). The wagons discharge from the whole length of an upper storey into the storage space, the floor of which is above ground level and is inclined in order to facilitate the discharge of the coal into special wagons for transport to the ships.

8 At the docks, the arrangements for loading into ships vary according to whether the bunkers have hatches easily accessible from above and from the sides, or whether they are small and in the galleries. Manual labour is used in the last case, but otherwise a tipping arrangement and a pair of cranes are used.

(*c*) *Unloading*

9 The unloading of water-borne coal is a very important matter at a number of gas works and power stations, and the prospect of the erection of large power stations on the main rivers of Great Britain (such a site being necessary to obtain an adequate water supply, as well as to reduce transport charges) make it increasingly important.

10 D4 (p. 495) describes the principal means employed and the factors to be considered as regards capacity, cost, flexibility, etc. Locomotive cranes and transporters are compared. In smaller units, cranes are more able to cover the hatch area and save trimming. With larger sizes, however, there is little to choose. The competition between the two has led to the development in Great Britain of excellent types of fast, high-capacity, grabbing cranes, not made abroad. The transporter has a simpler mechanism than the crane, and can hoist higher and deliver higher on shore.

11 The one-man trolley type of transporter (p. 497) is favoured on the Continent, and in America it has been developed on the Great Lakes. The rope-operated type of transporter is used in America with high rope speeds and large capacities.

12 The telpher (p. 498) is suitable for small plants where rapidity of discharge is not important. Telphers store in a straight line, and thus cause coning and segregation of the coal.

13 For unloading railway wagons track hoppers may be used with bottom-dump wagons (p. 499). This method is adopted with the 20-ton wagons in the North of England. Track hoppers should only be used to clear coal and not for storage.

14 Tipplers, lifting one end of the wagon for end discharge, and designed to avoid the old difficulty of the buffers hitting the track above a certain slope, are described (p. 500). Dumpers (p. 501) are of two forms. They may lift the wagon in a cradle or revolve it in a cage. A recently-developed third type is described, which elevates the wagon before emptying it. It may be used to prevent breakage. The revolving type is commonly used at collieries for discharging the pit tubs on to the screens, and is often called a tippler.

(*d*) *Handling by the User*

15 The methods of fuelling locomotives of the Belgian State Railways is described in D1 (p. 462). Blended coal is distributed to 100 fuelling stations. At the smallest stations the fuel is reclaimed from a dump by cranes. At more important depots (p. 463), the coal is emptied from the track wagons into small special wagons, which are taken by a lift to a platform above the tenders. These loading platforms pay for themselves rapidly, especially by reduction of the idle time in loading and the

increased traction time. In the more important stations the coal is delivered to an underground hopper, elevated by a bucket elevator, and distributed to special loading towers by a scraper conveyor.

16 The equipment required for feeding, elevating and conveying coal and coke, is described comprehensively in D4 (pp. 501-510), To make the description even more comprehensive, a paragraph or two on appliances for measuring quantities of coal or coke might have been added.

17 The gravity bucket elevator is much used in gas works and power stations, but its use to bring out the ashes as well as elevate the coal is declining. Skip hoists are also widely employed for small stations, especially for lumpy material. The ordinary bucket elevator described is that commonly found in gas works and power stations, but a more rigid form is usually preferred at collieries, say for a washery, the buckets being then mounted on links placed on edge and driven over drum heads rather than on chains driven by sprockets.

18 Pneumatic conveying is described. Despite its simplicity the system is costly, and difficulties are experienced with certain materials and in air filtering.

19 The conveying of coal by mixing it with water and pumping, as done at the Hammersmith power station, is recommended for consideration.

20 The merits of belt conveyors are discussed (p. 508) at some length, and the need of a very careful design is strongly urged.

(e) *Blending Arrangements*

21 The advantages which research suggests will accrue to the carbonisation (and other) industries by using blended coals are impeded by the practical difficulties of carrying out the blending operation. This renders all the more valuable the description in D1 of the mixing plant employed by the Belgian State Railways (pp. 459-462).

(f) *General*

22 Attention may profitably be directed to the arrangements made by the Belgian State Railways to ensure the supply of a uniform coal to their locomotives (D1). This necessitates the blending of coals from 200 sources and their distribution to 100 sub-stations.

One large central laboratory and three analytical laboratories are engaged in examining coal samples which are required partly to control the mixing and partly to determine the price paid for the coal according to a pre-arranged scale (price increased or decreased by $2\frac{1}{2}$ per cent. per 1 per cent. of ash below or above $12\frac{1}{2}$ per cent., and decreased by 1 per cent. per 1 per cent. water above 5 per cent.). These arrangements must be very costly, but they show how much more attention is given to the study of the correct use of coal than is the case with many British fuel consumers.

23 No mention is made in any of the papers of the storage, transporting and handling of powdered fuel, and some attention might profitably be devoted to this in the discussion.

DISCUSSION

WEDNESDAY, SEPTEMBER 26 (MORNING)

Section D

STORING AND HANDLING OF SOLID FUELS BY THE USER

Immediately after the meeting of Section C, a meeting of Section D, was held, also under the Chairmanship of Prof. R. V. Wheeler. The General Report on the subject was presented by Dr. W. R. Chapman.

DR. R. LESSING (Great Britain) opened the discussion again as Vice-Chairman, and remarked that the subject of the storage and handling of coal was not entirely an engineering one. The question of spontaneous combustion during storage had attracted a considerable amount of attention, and as regards ships the Fuel Research Board had done a considerable amount of work in investigating the problem of fires in ships coming into British ports. Blending of coals, in order to obtain from several sources a homogeneous material, was entirely a matter for the engineer; whilst facility in drawing samples was another important point in relation to storage. No amount of standardisation of analytical methods would avail as long as we were not in a position to draw representative samples from the consignments. The breakage of coal in transport was a serious matter. He did not think he exaggerated when he stated that the commercial side of the coal trade was based on the question of size of coal. Personally, he had often maintained that the size which was so greatly desired by the buyer of coal and particularly the foreign buyer was really nothing but an implied guarantee of purity in the absence of chemical analysis. Nevertheless, it was wanted and the commercial community had to satisfy the want and try and preserve the coal in the sizes in which it was mined. The handling arrangements to-day were very faulty in this respect, and it was a fact that coal lost as much as 10 per cent. of its useful sizes by disintegration between the colliery and the port, whilst another 10 per cent. might be knocked off in the few seconds during which a coal truck was discharged into the hold of a vessel. From the commercial point of view this was a very serious matter, and the proper design of handling methods which would preserve the coal in its original sizes and lead to a minimum of breakage was of the utmost importance. None of the papers dealt with the storage, transport and handling of powdered coal, but it would be of great use if the discussion elucidated some of the more recent experiences with the pumping of coal or

transport by pneumatic means. On the Continent, and particularly in Germany during the last three or four years, the transport of powdered brown coal or powdered semi-coke made from brown coal had extended to a very remarkable degree, and the number of specially designed tank wagons for this purpose was rapidly increasing. In this country, he was in a position to say that steps had been taken in this direction and at the moment special wagons were being put into service for the conveyance of coal dust from the colliery to the consumer, that is, dust wagons had been specially designed for the purpose in order not to allow the dust to consolidate to a mass which would not be handled by air currents at the consumer's end, the wagons being discharged by the simple application of compressed air into the bunker.

Mr. W. S. Edwards (Great Britain) said that in coke oven products in the United States, it had long been the custom to provide suitable means for mixing the coals, and to make provision for adjusting the mixer to secure such varying degrees of blending as might be required. At some plants as many as six different kinds of coal were mixed together to make a charge while in a great many instances it was common practice to mix four kinds. The necessity for exactly proportioning the different kinds of coal making up a charge and of being able to alter these proportions easily, yet definitely, to any new combination required by a change in coal received and also to mix together intimately the different kinds of coal, led to the development of the measuring coal mixer of which many examples had been working for some years in the United States by-product plants. The various qualities of coal to be mixed, whether four or more, were segregated in a series of coal bins each having a capacity of from 50 to 100 tons. These coal bins might be arranged above ground level, in which case they were fed by some suitable system of inclined belt conveyors, or in some instances they were arranged below ground level and were super-imposed by a suitable layout of railway tracks from which the coal could be dumped direct from the railway wagons into the raw coal bins. The underside of the bins terminated in suitable chutes provided with radial cut-off gates which were installed for the purpose of isolating any particular bin. Following the radial cut-off gate was a special adjustable gate which regulated the thickness of the stream of coal on a short belt conveyor which was provided with special idlers and steel skirt boards enabling it to carry a thick bed of coal. The height of this bed was determined by the special adjustable gate. Thus, the speed of the belt being known and the cross-sectional area of the bed of coal carried being easily determined by adjusting the gate, the volumetric measurement of the coal was exact for each conveyor and might be increased or decreased at will. There would be as many belt conveyors as there were different classes of coal to mix, all of which converged to a central point where they delivered their coal to a common chute leading to the Hammer Mills which prepared the coal *en route* to the ovens. At some plants the exact proportioning of the different kinds of coal to be mixed

was of great importance. A change of mix, such as might be accidentally caused by the stoppage of one kind of coal, might make a swelling charge or create some other serious contingency. To guard against these happenings, the volumetric and speed controls were locked after being set, and could only be altered by the superintendent, chemist or whoever had charge; the chutes from the bunkers overhead were very large, to give the coal free passage and avoid arching, there was an arrangement on each conveyor which in the event of a failure of coal for that conveyor would make an electrical contact that rang a large alarm bell and automatically shut down the whole mixer; and also in the event of any conveyor stopping from any cause whatsoever, the alarm bell rang and the remaining conveyors were immediately automatically stopped. As a rule the coal was cleaned of foreign matter and broken to $1\frac{1}{2}$ in. or $1\frac{1}{4}$ in. before mixing. In the case of a number of installations, the coal after leaving the track hoppers was conveyed by a system of inclined belt conveyors to the top of the mixer house where there was installed a Bradford breaker. These breakers removed all foreign matter such as pieces of iron, steel, wood, slate, bone, coal, sulphur balls, etc., break the coal to $1\frac{1}{4}$ in. and discharge to the raw coal bunkers feeding the measuring mixer. Generally there was only one belt conveyor to the breaker, and one kind of coal only was handled and broken at a time as far as the raw coal bunkers. The hammer mills directly under the mixer pulverised the coal to the size required, and discharged to the belt conveyors leading to the fine coal bin the oven charging machines.

An alternative system which was sometimes adopted, consisted of arranging a series of bins at track level each feeding into a reciprocating or shaking feeder provided with a variable stroke by means of which a fairly close regulation of the amount of each quality of coal be delivered might be secured, these feeders discharging their coal on to a common belt conveyor leading to the pulveriser house.

As regards loading plant, probably this was not covered in Paper *D*4 because of it being a form of handling more necessary to a producer or shipper of fuel than to the user. The loading staithes on our own north-east coast and the coal hoists of Wales were well known, but perhaps the belt conveying method of loading ships with coal, ores, stone and other bulk materials was not so well known on this side of the Atlantic. There were, however, several such installations in Great Britain and numbers in Spain and on the African coast of the Mediterranean, a very large belt conveyor ship-loading plant for coal at Durban, South Africa, and another large one on the Island of Spitsbergen in the Arctic Ocean.

In most of these a system of belt conveyors conveyed the coal from the truck hoppers or open storage piles direct to the dock side and loaded into ship by means of a hinged belt conveyor that was raised or lowered to suit the height of tide or height of ship and to reduce breakage. A telescopic chute was often used to reduce breakage. Sometimes this hinged boom conveyor was mounted on a travelling tower which would move from hatch to hatch and save moving the

ship while being loaded. Great capacities were obtained with conveyor-loading, 300 to 1,000 tons per hour being common, while the record was some 3,600 tons of coal into a ship in a single hour in a plant at Baltimore. Labour was very productive with this type of loading plant. At a ship-loading plant in Spanish Morocco with which he was familiar, 40-in. wide Robins belts were used. These took iron ore from the storage bin and loaded it into ship at the rate of 1,000 tons per hour, loading a 5,000-ton ship in half a day, all the operations being handled by eight men.

Capt. S aw (Great Britain) referring to spontaneous combustion in ships, and the investigations of the Fuel Research Division mentioned by Dr. Lessing, said that some 250 ships had been during the period July 25 to March 28 examined as a result of there having been fires in bunkers. The causes of these fires divided themselves into three classes. In the first place one of the least known causes of fire was the fact that if, under certain circumstances which not infrequently prevailed, fresh coal was shot into a bunker in which there was some coal left from the previous voyage a tendency existed to create a rise in temperature owing to oxidation at the junction of the two coals. Another cause was the passage of air through the coal due to leaky bulkheads, but the most common cause of fire was one which was so simple that it was surprising it should be allowed to exist. Coal was often stored in a close proximity to boilers and other sources of heat without any attempt at suitable lagging or air casing, with the result that it became heated to the self-ignition point. So far it appeared that ship owners were not sufficiently alive to this danger to guard against it. Something like 60 per cent. of the fires in bunkers on board ship were due to this cause, which was certainly preventable.

Lieut.-Commander H. W. Brooks, U.S.N.R. (U.S.A.), speaking with regard to the use of pulverised fuel said there were two systems in use, *viz.*, the "direct fired" or "unit" system which involved no storage, and the so-called "storage," "indirect fired" system or "bin and feeder" system, which did. Powdered coal in America was used originally in the cement industry, and there the storage system was almost universally employed. It was also used in the metallurgical industry which, with he believed two exceptions in America, used exclusively the storage system. In the early days of the use of powdered fuel for boiler plants, storage systems only were used, but more recently, especially for the smaller installations, the "direct fired" or "unit" system had been more popular. He had made an estimate not long ago for the National Coal Association of America of the number of boiler plants operated by powdered fuel, and it was found that there were three or four "direct fired" systems in use to every one "indirect fired" installation. However, generally where the unit system was applied, the quantity of coal used was relatively small, so that in total number of tons burned annually there was probably as much fuel used for boiler purposes by way of the one system as by way of the other.

The latest application of powdered fuel was to marine purposes.

The earliest experiments were upon H.M.S. *Skylark*, during the war. She operated within a short radius of Great Britain, using coal ground on land. Experiments were carried out at the same time in the United States steamship *Gem*, a scout patrol, which also used coal ground on land. Both these experiments were carried out at a time when we did not know a great deal about high heat releases per cu. ft. of furnace volume in powdered coal furnaces. After the war it was found uneconomical to continue this method of firing marine boilers as commercial practice. The matter, however, had been taken up again during the past three or four years and a certain amount of success had been obtained with the "unit" or "direct fired" system. One of the main difficulties for marine purposes was to divide the pulverised coal up equally and uniformly into a number of streams to the various burners or furnaces, and a very large number of devices had been tried with that object in view. He had seen a whole stack of patents on the subject of securing a continuously equal distribution between subdivided streams. A number of experiments, looking for the solution of this problem, had been carried out at the Philadelphia Navy Yard, which now gave promise of considerable success. This problem of distribution had also been the cause of most of the difficulties on the s.s. *Mercer*, with which many people were familiar. This whole marine problem was a matter for international co-operation. Those who were working at the matter in the United States were perfectly willing to exchange their ideas and experience and would like to draw upon the experience and experiments of other countries.

Another application of powdered fuel which had been attempted in America, but which he believed had been since carried out with greater success in Europe, was in connection with railway locomotive firing. So far that had had to be a true storage system, the locomotives being fed with powdered fuel from central pulveriser stations. Some ten years ago, for approximately from three to five years, efforts had been made to work powdered fuel successfully on the Missouri, Kansas and Texas Railway, on the Santa Fe Railway and the New York Central Railway, but up to date it had not worked with any degree of success. In this case it was not so much a question of distribution to the burners as that of heat release per cu. ft. of furnace volume, and what the success with railways was likely to be would depend upon the extent to which this problem was overcome. He was hoping that soon some of those on this side of the Atlantic would be able to throw more light on that matter.

Speaking of the matter in which the storage system is working in various undertakings in the United States, the speaker said that in the early days, bucket conveyors were largely used and there were also pneumatic conveyor systems using all the air for combustion as "carrier" air. Practically all the fires and explosions which occurred with powdered coal in the early days, which gave it a bad name then, were due either to sparks being transmitted through the transport system or to heat generated by the bearings

of the bucket conveyors. There was an interesting story as to how the present solution of the conveying problem of powdered coal was arrived at. For a period of about a year six investigations were put to working out six different systems, but none of them got particularly good results. One day, due to carelessness, a leaky air hose was dropped into an open barrel of powdered fuel and later the barrel was accidentally tipped over. To the surprise of the inventor of the system, Mr. Alonzo Kinyon, now deceased, who chanced to observe it, the powdered coal ran like water or a fluid. Further experiments were at once undertaken and it was found that by aerating the coal with a quantity of air amounting to a fraction of 1 per cent. of that necessary for combustion, the powdered coal could be made to flow in a quite satisfactory manner. Only one other attempt had been made before that, *viz.*, the so-called Quigley system, which used compressed air and "blow tanks" under pneumatic pressure to force the coal through in slugs. He did not wish to give the impression, however, that this was obsolete, because it was still being used in some cases with great success. However, 90 per cent. of the coal transport as regards powdered fuel in America was now by the Kinyon system. As regards the handling of the coal in the bins, there was insufficient air in it to cause combustion spontaneously and fires which now occurred were due to sparks from outside sources. Generally speaking, however, the danger of fire had been eliminated, because the bins were kept air-tight and as soon as a fire developed it could be at once quenched by cutting the air off.

On the motion of Mr. R. P. Sloan, C.B.E. (Great Britain) a hearty vote of thanks was passed to the Chairman, Vice-Chairman, authors of the papers and speakers in the discussions.

SECTION E

THE OIL INDUSTRY ECONOMIC AND GENERAL CONDITIONS

E1 THE ECONOMICS OF THE OIL INDUSTRY; PRICE OF PETROL.

E2 THE OIL INDUSTRY IN JAPAN.

THE NUMBERS ARE THOSE GIVEN TO EACH PAPER FOR USE AT THE FUEL CONFERENCE

THE ECONOMICS OF THE OIL INDUSTRY
PRICE OF PETROL

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS

E. H. DAVENPORT

*Paper No. E*1

CONTENTS

INCREASE IN CONSUMPTION—HOW THE GREATER DEMAND HAS BEEN MET—PRICE FLUCTUATIONS—COSTS OF PRODUCTION—DETERMINATION OF PRICE—INFLUENCE OF SYNTHETIC PETROL—PRICE COMPARED WITH OTHER COMMODITIES—ZUSAMMENFASSUNG

As the major problem of the oil industry since the war has been to produce sufficient fuel for the automobile industry, this paper will be directed to the study of the price of gasoline (petrol). To the man in the street the fluctuations in the price of gasoline must be a mystery. The popular impression is that these price movements are made at will by the big oil combines whose only economic principle is expressed in the dictum: "the price of petrol is what it will fetch." That is a crude way of expressing the fundamental truth that oil prices are determined by the conditions of supply and demand. The trouble is that these conditions are generally too complicated for the man in the street to comprehend.

(1) *Increase in the Consumption of Gasoline.*

The United States handles over 80 per cent. of the world's gasoline trade. The following table will give some idea of the enormous increase which has occurred since 1899 in the American domestic consumption and exports of gasoline as compared with the other major products of crude oil—kerosene, fuel oil and lubricating oils.

It will be seen from this table that the consumption of gasoline (American domestic consumption and exports representing over 80 per cent. of the world's turnover) in 1927 was 5025·7 per cent. greater than in 1899 and 885·3 per cent. greater than in 1914. This

TABLE I.

U.S. DOMESTIC CONSUMPTION AND EXPORTS OF MAJOR REFINED PRODUCTS IN THOUSAND BARRELS

	Gasoline.	Kerosene.	Gas and fuel oil.	Lubricating oil.	Total.
1899*	6,679·5	29,966·5	7,227·0	4,745·0	48,618·0
1904*	6,954·0	32,317·8	8,564·4	7,503·0	55,339·2
1909*	12,848·0	39,894·5	40,515·0	12,775·0	106,032·5
1914*	34,748·0	46,063·0	88,184·0	12,337·0	181,332·0
1919	90,629·5	56,538·5	177,718·5	20,148·0	345,034·5
1920	116,461·2	53,911·8	205,692·0	24,302·4	400,367·4
1921	120,194·5	47,377·0	215,788·0	18,943·5	402,303·0
1922	141,693·0	56,173·5	256,595·0	23,433·0	477,894·5
1923	177,025·0	55,224·5	290,649·5	25,586·5	548,485·5
1924	213,378·0	62,183·4	326,838·0	27,157·2	629,556·6
1925	255,317·5	61,174·0	342,297·0	30,295·0	689,083·5
1926	305,140·0	60,371·0	375,913·5	31,974·0	773,398·5
1927	342,370·0	57,086·0	388,871·0	31,426·5	819,753·5

* Production figures. Others not available.

represents an average annual increase of 68·1 per cent. for the thirteen years since 1914. No other industry has had to meet such a call for manufacturing expansion. I am not making any unfair comparison as between 1914 and 1927 because the consumption of gasoline in 1914 was not abnormally low. In fact, the increase in its consumption for the ten years prior to 1914 had averaged 40 per cent. per annum.

This remarkable increase in the demand of gasoline followed upon the rapid growth of the American automobile industry, which is shown in the next table:—

TABLE II.

	Registration of all cars. in U.S.	Domestic demand for gasoline per car. gallons.
1916	3,584,567	—
1917	4,970,671	475·8
1918	6,105,588	512·5
1919	7,596,503	452·2
1920	9,206,141	461·7
1921	10,505,630	429·9
1922	12,299,770	436·7
1923	15,312,658	429·9
1924	17,605,495	441·3
1925	19,857,915	473·5
1926	22,046,957	498·8
1927	23,302,668	536·9

The registrations of American motor vehicles in 1914 were 1,711,339; those in 1927 were 23,302,668, showing an increase of 1261·7 per cent. over those of 1914. The total registrations of all motor vehicles for the world are estimated at 29,687,499 for 1927, as compared with 2,177,000 for 1914, an increase of 1263.7 per cent.

(2) *How the Greater Demand for Gasoline has been met.*

Before the war the only way in which the rapid increase in the demand for motor fuel was being met was by the production of a larger amount of crude oil for the manufacture of what is called "straight-run" gasoline. The crude oil output of the United States was increased from an average of 156,358 barrels a day in 1899 to 728,116 barrels a day in 1914, an increase of 365·7 per cent. Since 1914 the American output of crude oil has risen to a daily average of 2,460,000 barrels, which is more than $3\frac{1}{3}$ times as large as the output in 1914, but while this increased crude oil production was more than sufficient to meet the demand for kerosene, gas and fuel oils, it would not have been sufficient to meet the greater demand for gasoline if gasoline had been manufactured by the same methods as in 1914.

In 1914 the amount of gasoline recovered in the United States was equal to 18·2 per cent. of the amount of crude oil refined, a recovery which showed a considerable improvement in the refining methods since 1899. But that 18·2 per cent. recovery to-day would be hopelessly inadequate to meet the demand for gasoline that has developed since 1914. On the basis of an 18·2 per cent. recovery it would have been necessary to refine more than 5,153,800 barrels of crude oil a day in 1927 in order to provide the 938,000 barrels a day of gasoline which were consumed in and exported from the United States. In other words, if only 18·2 per cent. of gasoline were being recovered from crude oil to-day the American oil industry would have to double its 1927 output, although that was a record year of tremendous activity in the American oil fields.

It had become obvious before the war that in order to meet the rapidly increasing demand for motor fuel, a larger amount of gasoline would have to be recovered from the "wet" casinghead gas or dry natural gas, and that some part of the heavier products of the crude oil remaining after the gasoline had vapourised off would have to be converted or "cracked" into gasoline. Before 1912 cracking had only been used to a certain extent in the production of kerosene, but since the war the cracking of fuel oil for the production of gasoline has been steadily developed. Table III. shows the total amount

of gasoline produced in the United States since 1919 and the proportions accounted for by the production of "straight-run" gasoline, natural gasoline and cracked gasoline. The final column shows what percentage of the crude oil throughput at refineries the "total" column represents:—

TABLE III.

U.S. GASOLINE PRODUCTION—IN THOUSAND BARRELS

	Straight run.	Cracked (a)	Natural gas gasoline	Total.	Per cent. of throughput.
1919	81,288	10,000	2,957	94,235	25·9
1920	98,098	15,000	3,153	116,251	26·6
1921	100,187	20,000	2,517	122,704	27·5
1922	114,010	30,000	3,662	147,672	28·4
1923	139,416	35,000	5,487	179,903	30·4
1924	160,654	40,000	12,671	213,325	31·7
1925	171,383	68,582	19,636	259,601	32·5
1926	181,599	93,736	24,399	299,734	35·3
1927	197,282	101,224	32,161	330,667	36·7

(a) Estimated 1919-1924.

It will be seen that since 1919 the production of natural gasoline has increased by 987·6 per cent. and the manufacture of cracked gasoline by 912·2 per cent. By these means the production of gasoline per barrel of crude oil raised from the ground has risen from 25·9 per cent. to 36·7 per cent. That is how the enormous increase in the demand for motor fuel has been met since the war. It is outside the scope of this paper to go more fully into the development of the natural gas industry or of the various "cracking" processes. From the economic point of view the important fact to appreciate is that the manufacture of natural gas and "cracked" gasoline has conserved enormous quantities of crude oil which it would otherwise have been necessary to produce and refine. By these means the oil industry has enormously cheapened the price of gasoline for the consumer. If the American oil industry had had to produce double the quantity of crude oil it raised in 1927—which it would have been compelled to do if the manufacture of natural gas and cracked gasoline had not been developed—the prices of crude oil and gasoline in the United States would now be soaring to famine heights and the consumer in Great Britain would probably be paying more than 3s. a gallon for petrol exclusive of tax.

(3) *The Fluctuations in the Price of Gasoline.*

Broadly speaking, the fluctuations in the prices of gasoline are caused by the variations in the supply of crude oil, which is its basic

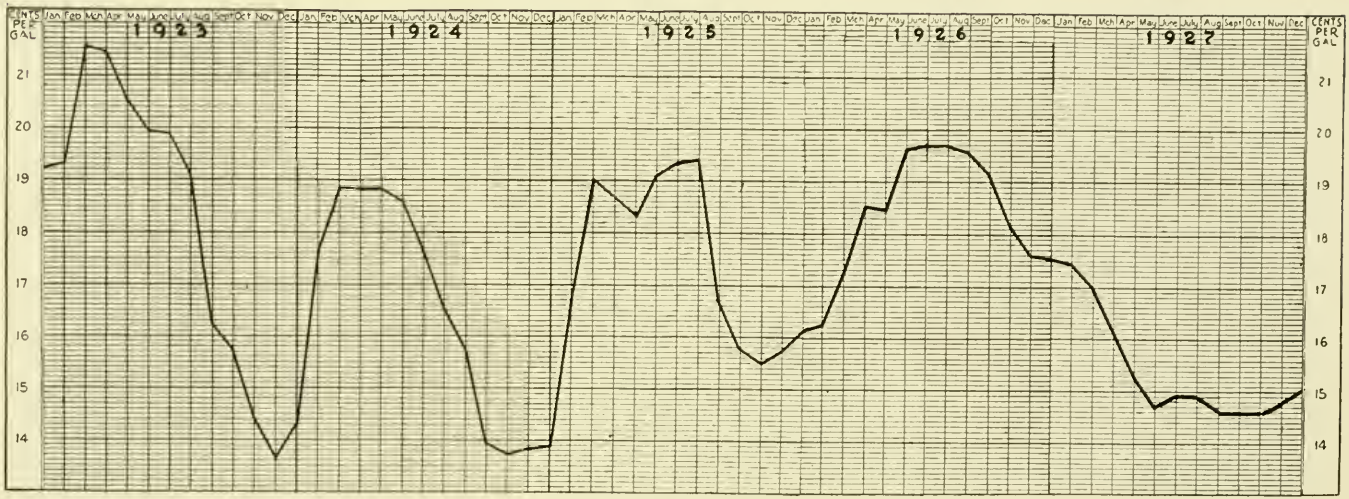
raw material. The supply of crude oil varies from year to year because of the extreme element of chance in the finding of new oil deposits and the intensive competition that usually develops in the American oilfields. No geologist can foretell with certainty that oil will be discovered in any particular place or at any particular depth or in any particular quantity. If oil is suddenly discovered in America in a district which is divided up in chequer-board fashion the man who gets down first and secures the first flush production probably does better than those who follow. Hence there is in all competitively-owned oilfields a headlong race down to tap the oil. The general result is a flood of oil poured suddenly on the market and a consequent slump in crude oil prices. The latest orgy of competitive production has been in the Seminole fields, Oklahoma. Although these Seminole fields produced less than one-seventh of the total crude oil production of the United States in 1927, the flood of oil suddenly poured on the market as a result of their feverish development caused a 50 per cent. drop in the prices of light oils in the Mid-Continent districts. It is obvious that the prices of crude oil must always fluctuate violently on account of the chance finding of crude oil and the competitive nature of oil drilling. Hence the price of gasoline must move accordingly, and the only reason why the price of gasoline does not always fluctuate as violently as that of crude oil is because the large oil marketing concerns endeavour to stabilise as far as possible the price of gasoline in the interests of the consumer. Table IV. shows in chart form how the prices of a representative light crude oil and of gasoline have fluctuated since 1923.

(4) *The Costs of Production.*

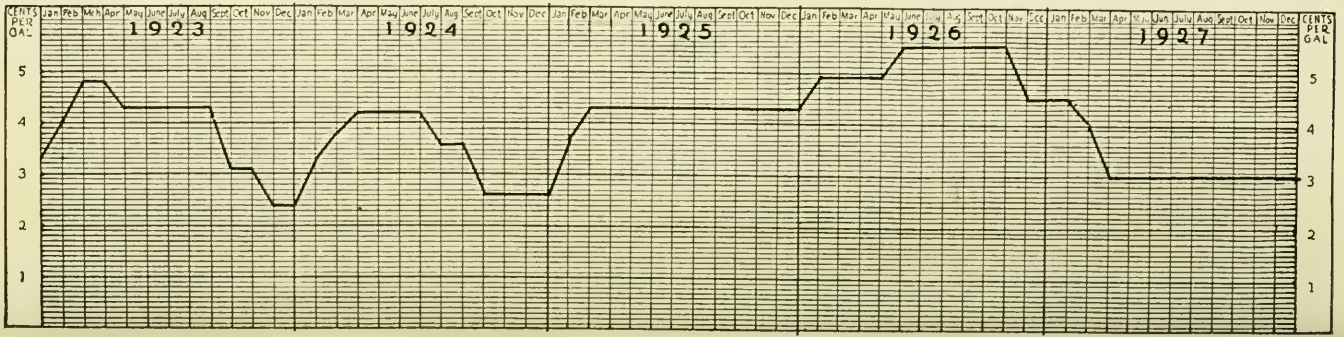
It is necessary at this point to emphasise the fact that gasoline prices do not and cannot bear any systematic relationship to the actual costs of production. To begin with, the actual costs of crude oil production can never be exactly ascertained. The normal tendency is for the price of a commodity to correspond with what is called its marginal cost of production plus a reasonable percentage for profit. The marginal cost of production is defined as "the cost of production of that part of the annual output which is wrested with most difficulty from the lap of nature." In the case of crude oil, it is impossible to say what is the cost of "that part of the annual output which is wrested with most difficulty from the lap of nature." The average cost of the new oil producing wells drilled in the United States since 1916 is estimated at $15,000, per well. On that basis

TABLE IV.

Average tank wagon gasoline price in fifty representative cities exclusive of taxes. Prices given in cents per gallon.



Average price for 36 gravity Oklahoma-Kansas crude oil. Prices given in cents per gallon.



the total cost of the new oil wells brought in since 1916 in the United States would amount to $2,887,395,000. But in this period 66,774 dry holes were drilled and it is estimated that the average cost of these dry holes would be $10,000 per hole. On that basis the dry holes have cost the oil industry in America during the past eleven years about $667,740,000. The cost of crude oil, therefore, depends largely on the cost of dry holes and non-tangible development expenses.

The actual cost of drilling varies from field to field and from well to well. For example, the cheapest well drilled in the United States last year cost $2,500, but the wells in Sante Fe Springs, California, which are 4,000 to 5,000 ft. deep, cost anything from $85,000 to $125,000, and in Long Beach, California, the deepest wells cost $125,000. The deepest producing well in the world, which is in Ventura Avenue, California, measures 7,957 ft., and the Associated Oil which drilled it, is probably too modest to say how costly the well was. The only certain fact about production costs is that the average cost of drilling wells has increased in the last fifteen years. The average cost, for example, of drilling a well in California in 1913 was $38,494 and in 1927 it was $56,300. In Kansas in the same period the cost of drilling increased from $20,500 to $24,750, and in Oklahoma from $4,667 to $32,300, and in the United States as a whole from $4,765 to $18,725.

It is generally taken that the costs of producing a barrel of crude oil in America are made up of the following proportions:—

22·5 per cent. direct lifting expenses.
18·5 per cent. depletion of property.
15·4 per cent. depreciation of physical equipment.
14·55 per cent. non-tangible development expenses.
13·2 per cent. dry holes and abandonments.
6·4 per cent. general expenses.
5·13 per cent. year's proportion of bonus.
4·12 per cent. rentals on undeveloped acreage.

But these proportions vary enormously in different fields. In the last few years in Mexico, for example, the cost of dry holes must have been nearly 50 per cent. of the total. It is, of course, possible for an individual oil company at the end of its financial year to say that it has spent so many million dollars in drilling and applied so many million dollars towards depletion of properties, and that the year's production of crude oil has therefore cost so much per barrel. But the price of crude oil is posted over a whole district in which a

hundred or more individual oil companies may be operating. For example, prices are posted by the Magnolia Petroleum Company for Mid-Continent crude oils of varying grades, and these prices apply to Oklahoma, Kansas, North and East Central Texas. As the fortunes of different oil companies, even in the same oil fields, vary considerably, the posted prices of crude oil can bear no exact relationship to the marginal costs of production. Thus it sometimes happens—as it has happened this year in America—that oil producing companies have to sell their crude oil for a time below their estimated costs of production.

(5) *How the Price of Gasoline is Determined.*

It will, therefore, be obvious that the price of gasoline, like that of its primary raw material, can bear no systematic relationship to the costs of production. In fact it may be argued that it bears no relationship at all to the actual costs of manufacture. In the first place, the products which the oil refiner obtains from the stills vary greatly according to the composition of the crude oil and the method of refining. There are some crude oils that yield no gasoline, others that yield no lubricating oil, and others that yield no kerosene. Each contains varying amounts of such impurities as sulphur compounds. Pennsylvania, West Virginia, Mid-Continent and Rocky Mountain fields furnish light crude oils which are easy to refine. The Gulf Coast, California and Mexico yield oil of a high sulphur content. The Smackover field of Arkansas gives a heavy oil which was sold at first only for burning until it began to be cracked for gasoline. Paenhandle, Texas, crude oil with its high sulphur content, salt and excessive wax, was at first considered fit for use as fuel only. Most of the oils from the recently discovered fields in West Texas are high in sulphur and contain hydrogen sulphide gas which corrodes the equipment.

Theoretically, it might be said that in any particular year an average barrel of American crude oil yielded, say, 46 per cent. gas and fuel oil, 27 per cent. gasoline, 10 per cent. kerosene, 4 per cent. lubricating oil and varying quantities of paraffin wax and asphalt, and that if the price of a barrel of crude oil for that year averaged, say $1.00, the cost of manufacturing gasoline would be 27 cents, the cost of manufacturing gas and fuel oil 46 cents per barrel, kerosene 10 cents per barrel and lubricating oil 4 cents. That theoretical calculation would merely show that some of the products would be selling at present market prices at a dead loss. Indeed, some products have always sold at prices under the theoretical

cost of production, if that cost be distributed among the various products according to the percentage of their yield from the crude oil.

In the second place, gasoline as a rule has to bear a price which will return a much greater proportion of the total receipts than is represented by its proportionate recovery from the crude oil. The products contained in the crude oil all come out of the ground together and the only difference in their theoretical cost is their refining cost. Why, then, is petrol retailed at, say, £15 a ton and fuel oil at only £3 12s. 6d. a ton? It is merely that the relation between the demand and supply of petrol is such that it can and must pay a much higher proportion of the cost of the crude oil than the proportion in which it is actually contained in the crude oil as it comes out of the ground. The relative prices of gasoline, kerosene, fuel oil and lubricating oil are merely expressions of the effect of the operation of the law of supply and demand. It is necessary to pay a relatively high price for gasoline in order (1) to make the producer of crude oil supply the refineries with so much crude oil in the year, (2) to make the refiners erect cracking plants and crack so much fuel oil in the year—for the satisfaction of the urgent demands of the automobile industry. If the supply of gasoline is temporarily short and refiners have to reduce their stocks, then the price of gasoline must advance and force up the price of crude oil in order to make the producer increase his output. The history of the American oil markets in the last twelve months illustrates this point. The price of gasoline of U.S. motor grade 58-60°B. *ex* Oklahoma refinery rose steadily from 5½ cents per gallon in January to 9½ cents per gallon in August. Apart from a minor adjustment in the prices of heavy and light crude oils in February, the price of Mid-Continent crude oil was not advanced until July and Californian oils not until August. But the manufacture of "cracked" gasoline from cracking plants increased in the first six months to 55,570,000 barrels as compared with 48,891,000 barrels in the corresponding period of 1927. In other words, the steady advance in gasoline prices forced up the price of crude oil only when it was discovered that the supply of cracked gasoline from fuel oil could not be increased quickly enough to meet the temporary shortage of gasoline in the market.

It is, of course, possible that the development of the Diesel engine or some other development yet in its infancy will make the demand for fuel oil greater than that for petrol, in which case fuel oil may be selling at £15 a ton and petrol at £3 12s. 6d. a ton. But, as I have stated at the beginning of this paper, the main problem of the oil

industry since the war has been to provide sufficient fuel for the automobile industry. That is why the price of gasoline has to bear a price which will return more than 50 per cent. of the total receipts derived from crude oil, as the next table will show.

TABLE V.

VALUE OF MAJOR REFINED PRODUCTS AT U.S. REFINERIES.

	Gasoline.	Kerosene.	Gas and fuel oils.	Lubricating oils.	Total.
1899	$15,991,742	$74,694,297	$7,550,664	$13,351,831	$111,588,534
1904	21,314,837	91,366,434	9,205,391	23,533,091	145,419,753
1909	39,771,959	95,547,010	36,462,883	38,884,236	209,666,088
1914	121,919,307	96,806,452	84,017,916	55,812,120	358,555,795
1919	766,006,055	235,663,055	318,124,339	196,242,439	1,516,035,888
1921	881,401,680	151,594,503	377,264,190	194,609,241	1,604,869,614
1923	929,900,078	146,941,897	345,666,436	204,494,849	1,627,003,260
1925	1,268,647,929	161,880,676	488,957,806	252,104,578	2,171,580,989

It may be argued theoretically that the only fixed ultimate constant which cannot change is that in the long run the prices realised for the whole of the products of the crude oil must be such that taken together they cover the cost of the crude oil and its refining, and of the carrying of the refined oil products to the consumer. Otherwise the big companies which produce, refine and market crude oil will be forced out of the oil business. Theoretically that is correct, but because the costs of production are never exactly ascertainable, it very often happens that the big companies go on producing crude oil for a time at a loss. A large number of important oil companies in America showed losses in the last two quarters of 1927 and in the first quarter of 1928.

If I may restate my conclusion, the price of petrol is determined not by the theoretical cost of production of the crude oil and its manufacture into refined oil products, but by the interplay of extremely complicated forces of supply and demand. If gasoline is in short supply the price must go up until the refiners crack more fuel oil and then must continue to rise, if that extra supply of cracked gasoline is not sufficient, until the price of crude oil is advanced and producers are thereby tempted to sink more wells. If the supply is in excess, the price of gasoline must fall until the refiners close down their cracking plants, and, if that does not solve the surplus problem, it must go down further until crude oil prices slump and so prevent the drilling of new wells or force producers into restriction of existing production.

(6). *The Influence of "Synthetic" Petrol.*

At present the price of gasoline is not appreciably affected by the production of substitute motor fuels. I do not consider that the manufacture of petrol from coal—either by the low-temperature carbonisation processes or by the hydrogenation process developed by the Farben Industrie—is likely to be sufficient to influence the price of gasoline for some considerable time. The coal distillation processes, for example, involve three distinct stages of production —the mining of the raw material (coal), the distillation of the solid and the refining of the liquid "oil" so distilled. The costs of mining the solid raw material must always be greater than the cost of mining crude oil as long as the coal is mined by underground labour while the crude oil is produced merely by drilling a hole in the ground. The distillation of the coal and the subsequent refining of the distilled oil must always be more expensive than the mere refining of natural crude oil. Hence the low temperature carbonisation processes will depend for their commercial existence upon the sale of the coke by-product—the smokeless fuel—leaving the oil products merely as subsidiary sources of revenue, just as the production of benzol from coal by the high-temperature carbonisation of coal process is merely a subsidiary source of revenue to the coke-ovens or the gasworks.

As regards the hydrogenation of coal—that is, the conversion of coal direct into refined oil products by the introduction of hydrogen into pulverised coal at high temperatures under pressure—the I.G. Farben has not yet published to the world their costs of production, so that it is impossible to say whether this form of "synthetic petrol" is a commercial rival of gasoline produced from crude oil. It is, however, actually being produced from brown coal in Germany by the I.G. Farben and is being marketed through a company in which the Royal Dutch Shell and Standard Oil groups are interested. The annual output of this synthetic petrol is to be brought up to 300,000 tons (2,100,000 barrels) per annum. At the present low prices of gasoline it is not believed that the hydrogenation of coal can be widely developed outside Germany, where the lignite fields provide a cheap and readily available raw material. The application of the hydrogenation process to the conversion of heavy fuel oils into gasoline seems to be an immediately more profitable way of utilising the wonderful invention of M. Bergius. That application is being undertaken at the moment by the Standard Oil Company of New Jersey.

(7) *Price of Gasoline compared with other Commodities.*

In conclusion, it may be useful to compare the price of gasoline to-day with the prices of other commodities that are in everyday use. I have already pointed out that (1) the increased efficiency of the oil refineries, through which a better recovery of "straight-run" gasoline is obtained from the crude oil while refinery losses have been reduced to a minimum, (2) the development of the "cracking" process by which the residual oils of the refining process are made to yield up a further supply of gasoline; and (3) the increase in the manufacture of natural gas gasoline, have all resulted in conserving enormous quantities of crude oil. There is not the slightest doubt but that the price of gasoline would be double or treble the price to-day if the oil industry in the last fourteen years had not been so mightily efficient. If the U.S. Bureau of Labour index numbers are considered it will be seen that gasoline shows the least increase in price since 1913 of any of the commodities in everyday use, and this in spite of the increased cost of drilling for crude oil:—

TABLE VI.

COMPARISON OF INDEX PRICES.
By years 1913 to 1927.

1913 PRICE LEVEL = 100.
Compiled from U.S. Bureau of Labour and U.S. Department of Commerce Statistics.

	Gasoline	Building materials.	Cloth and clothing.	Farm products.	All commodities
1913	100	100	100	100	100
1914	83	92	98	103	98
1915	75	94	98	104	101
1916	121	120	127	123	127
1917	132	157	175	190	177
1918	139	172	228	218	194
1919	142	201	253	231	206
1920	170	264	295	218	226
1921	143	165	180	124	147
1922	140	168	181	133	149
1923	112	189	200	141	154
1924	102	175·1	190·9	143·4	149·7
1925	106	175·1	189·6	158·1	158·7
1926	112	173·4	175·9	142·2	151
1927	112·2	166·0	169·0	137·9	146

It will be seen that the average retail prices of all listed commodities including household goods, building materials, clothing and farm products for the first nine months of 1927 were 46 per cent. above those of 1913, and this average would have been higher if it had not included gasoline, which has increased in price since 1913 by only 12·2 per cent.

ZUSAMMENFASSUNG

Da seit dem Krieg die ausreichende Erzeugung von Brennstoff für die Automobilindustrie das Hauptproblem der Ölindustrie war, ist dieser Bericht auf das Studium des Benzinpreises gerichtet. Die volkstümliche Ansicht darüber ist ja, dass die Preisbewegungen von den grossen Ölkonzernen willkürlich "gemacht" werden, die sich dabei nur danach richten, wieviel aus dem Publikum herauszubekommen sei. Damit wird aber nur die fundamentale Wahrheit auf etwas derbere Art ausgesprochen, dass sich die Ölpreise nach dem Verhältnis von Angebot und Nachfrage regeln.

Der Verfasser zeigt, wie die gesteigerte Nachfrage nach Benzin befriedigt wurde und wie der Benzinpreis festgesetzt wird. Zum Schluss vergleicht er den Benzinpreis mit denen anderer Gebrauchsgegenstände.

THE OIL INDUSTRY IN JAPAN

POWER ASSOCIATION OF JAPAN

KEIZABURO HASHIMOTO

Paper No. E2

CONTENTS

THE GEOLOGY OF JAPANESE OIL-FIELDS—DRILLING AND PRODUCING METHODS IN JAPAN—NATURAL GAS AND NATURAL GAS GASOLINE—REFINING METHODS IN JAPAN—DEMAND AND SUPPLY OF PETROLEUM IN JAPAN—RÉSUMÉ

THE GEOLOGY OF JAPANESE OIL-FIELDS

Geological Age

The formations producing oil or bearing some indications of its existence belong, with two or three exceptions, to the Tertiary and especially all the horizons producing oil, as well as the majority of those with oil indications, are classified under the Neogene; and only two or three localities in Hokkaido bearing oil indications are to be classified under the Palæogene.

Outside the Tertiary series, oil indications are found only in a few places, *i.e.*, in the Jurassic "Torinosu Limestone" Tosa-no-Kuni (Province of Tosa), and in the Cretaceous sand rock of Hidaka-no-Kuni (Province of Hidaka), Hokkaido and of Ishikari-no-Kuni (Province of Ishikari), Hokkaido. These, however, are at present considered to be negligible from the point of view of the oil industry.

Distribution of Oil-Fields

The distribution of oil-fields in Japan (Fig. 1) from North to South is as follows:

In Japanese Sakhalin, oil has been found up to the present only on the West Coast, while in Russian Sakhalin, it is found solely on the opposite coast.

In Hokkaido, oil areas are scattered all over the district on the western side of the "back-bone" mountains.

Entering Honshu, the oil area starts from the Tsugaru Peninsula, Aomori Prefecture, opposite to the Oshima Peninsula and extends along the Japan sea coast into Akita Prefecture, where in the south it occupies a comparatively narrow space, stretching into the Yamagata Prefecture. Here, not only the coastal territory but the Shinjo basin also shows indications of oil.

On the coast, near the boundary line of the Niigata and Yamagata Prefectures, granitic rocks appear, and there the oil area is interrupted but reappears southward in the Niigata Prefecture, where almost the whole area with the exception of mountain territory in the north and east can be regarded as oil bearing. In the Nagano Prefecture the oil is present in a large area stretching from Uyeda City in the east to the vicinity of Matsumoto City in the south. In the west of the Niigata Prefecture, the oil area is blocked by the Nihon Alpes mountains and turns towards the mountain region of the Nagano Prefecture.

Up to the present, no oil indication has been found in the Toyama and Ishikawa Prefectures.

As stated above, this oil area forms an almost unbroken zone, extending from Japanese Sakhalin in the north to the middle part of the Nagano Prefecture in the south, and is the most important oil-producing territory in Japan.

Outside this important oil zone, the following places are producing oil or give indications of its presence:—

(*a*) Churui-mura, Nemuro-no-Kuni (Province of Nemuro), Hokkaido,

(*b*) The neighbourhood adjacent to the summit of Mt. Akan, Kushiro-no-Kuni (Province of Kushiro), Hokkaido,

(*c*) The vicinity of the Isobe mineral spring, Usui-gun, Gumma Prefecture,

(*d*) The vicinity of Sagara-machi, Kuwabara-gun, Shizuoka Prefecture,

(*e*) The Wanibushi Copper Mine, Hikawa-gun, Shimane Prefecture,

(*f*) Taiwan.

Sagara is the only oil area on the Pacific coast. Oil has been produced here continuously for a very long time, although in rather small quantities.

The oil area in Taiwan is very important in southern Japan, the island exhibiting oil indications in many places, excepting the central mountain region.

MAP SHOWING DISTRIBUTION OF OIL FIELDS IN JAPAN

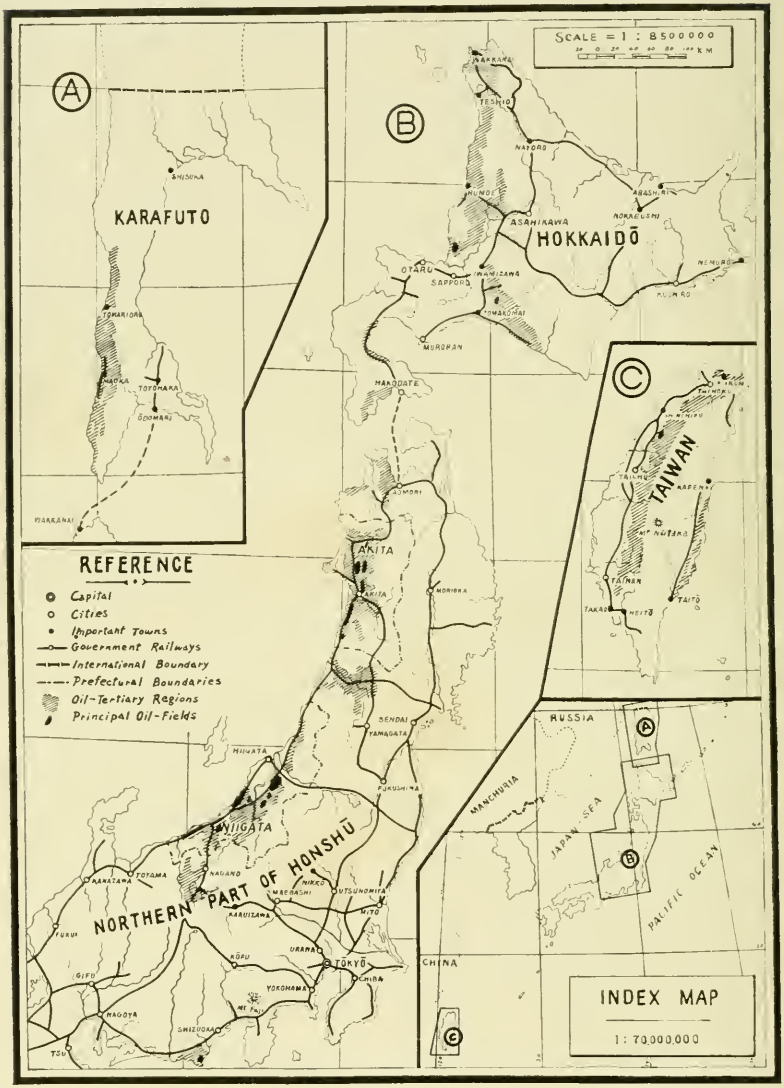


Fig. 1.

DRILLING AND PRODUCING METHODS IN JAPAN

Hand Drilling System

At present, by the hand drilling system, wells can be drilled to a depth of from 300 to 600 feet. Many attempts are and have been

made to improve the hand drilling system by adding motor, suction-pump, ventilator and other apparatus, but the hand driller can no longer compete with the machine drill in any of the larger fields of the world, and in Japan also the system is seldom adopted for wells, except under some exceptional circumstances.

Wells drilled by this system are square in section, the length of the side usually being 5 ft. at the top, gradually diminishing to 3 ft. at the bottom as the hole deepens. The excavation work is carried out by one or two men working at the bottom of the hole, and the earth is removed by means of a basket fastened to a wire rope suspended from the pulley of the derrick.

Sometimes, depending on the type of stratum being drilled, every 4 to 6 ft. a wooden frame, varying in size with the diameter of the hole, is inserted, and wooden cross-pieces and boards are used to case the well in order to protect it from caving. After the well has reached a depth of 20 or 30 ft., fresh air is sent down to the workers at the well bottom through a wooden pipe, by means of foot-bellows.

Percussion System

(a) Kazusa-bori

The majority of percussion system wells in Japan have been drilled by the American Standard Cable system, but one percussion system known as "Kazusa-bori" (Fig. 2) has also been used frequently.

The following is a brief description of the "Kazusa-bori" outfit:—

The derrick is about 30 ft. in height, about 3 ft. square at the top and about 10 ft. square at the base. A pulley is attached to the top, and on one side of the derrick, a wooden scaffold is set up, inside which a wooden polygonal wheel of 12 to 15 ft. in diameter, usually called the "Hene wheel," is installed. The bull wheel is located on the other side of the derrick, and is used for raising and lowering iron pipe and other heavy materials. At a point about 10 ft. above the wheel, several bamboo-poles jointed together are placed horizontally, with one end fixed firmly and the other placed so that the pole extends to a point just above the well centre. From this end, the tools are suspended, and drilling is effected by means of the elasticity of the bamboo-pole.

Inside the Hene wheel, a step-board is installed and on this, one or more workers walk backwards and forwards, thus turning the wheel and actuating the drilling tools and bailer. The bamboo attachment from which hang the drilling tools, is generally called the "Hene," and consists of a flat plate of "phyllostachys mitis"

with sheath, 1 to 1½ in. in width and ⅜ to ½ in. in thickness. The driller stands on the floor of the derrick, holding the hemp rope suspended from the end of the "Hene," and adjusts the length of rope as drilling proceeds.

KAZUSA-BORI OUTFIT

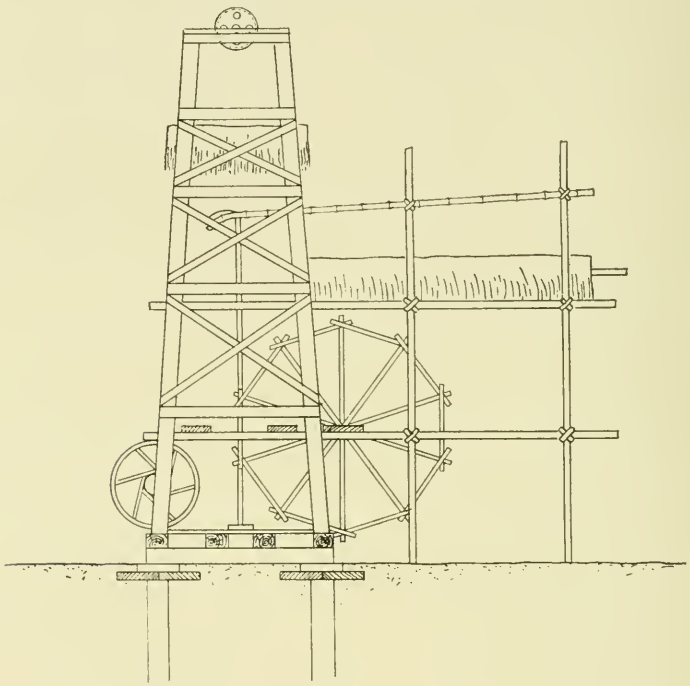


Fig. 2.

As there are many fittings peculiar to the Kazusa-bori outfit, the following will serve as a brief description of them:—

(*a*) THE "KABURA"

This is the drill which is fastened to the end of the drill stem and has a flat caudal cutting edge.

(*b*) THE "ISHIWARI"

The "Ishiwari" is the drill used for beds which are too hard to be drilled by the "Kabura." It is a steel bar of suitable length and diameter, forged flat at one end to the size of an axe.

(*c*) THE "SUIKO"

This is generally made of tin-plate reinforced by longitudinal steel bars, and acts as a bailer for removing mud

or oil, its size being determined by the diameter of the well. The lower part of the "Suiko" is pointed and is equipped with a valve.

The "Kazusa-bori" system has many merits, the chief being the low initial expenditure, and also the fact that motor equipment is not required. Recently, however, many improvements have been made: for example, the use of a small motor has reduced the number of labourers required, and many new and up-to-date fittings have been added.

Nowadays, wells of about 1,000 ft. can be drilled by this system, and it is adopted in many places in Japan, to drill comparatively shallow test wells or to clean existing wells.

(B) CABLE SYSTEM

The cable system was imported from U.S.A. in 1894, and now its adoption is almost universal in the oil regions of Japan. However, no important improvement or modification peculiar to Japan have been made either to its apparatus or to its operation.

ROTARY DRILLING SYSTEM

The rotary drilling system was first imported from U.S.A. to Japan in 1912 and since then because of its greater speed and depth of drilling, it is superseding other methods.

Here again, no important improvement or radical change in its construction and methods of operation have been brought about in Japan.

In Japan, hand drilling, Kazusa-bori, cable drilling and rotary drilling have developed in this order, but in some exceptional cases, cable-rotary combination systems, rotary-cable systems and diamond drilling systems are also adopted.

Out of the 3416 producing wells of the Nippon Oil Company, the census on 30th September, 1927, shows:—

By rotary drilling system	864
,, cable ,, ,, ...	2090
,, "Kazusa-bori"	418
,, diamond drilling system	3
,, hand ,, ,, ...	41
Total ..	3416

The deepest well ever drilled in Japan reached a depth of 1955 m., the average daily progress being 223 m.

Producing Methods

Producing methods used in Japan can be divided into three groups *viz:* (1) gusher, (2) pumping system, (3) air lift system. No other method, peculiar to Japan, has yet been invented.

NATURAL GAS AND NATURAL GAS GASOLINE

Production of Natural Gas

The production of natural gas from oil and gas wells of the Nippon Oil Company, its gravity and gasoline contents are as follows:—

October 31, 1927

Field.	Daily production of gas. cu. ft.	Gravity.	Gasoline contents. Imp. gallons per 1000 cu. ft.	Number of gas wells and wells producing oil and gas.
Nishiyama	2,553,000	0·75-0·9	2-6	308
Takamachi	1,650,000	0·6	0·2	2
Niitsu	1,173,000	0·65-0·75	0-2	190
Akita	1,810,000	0·60-0·80	0-4	713
Hokkaido	260,000	0·85	5	50
Shukkoko, Taiwan ...	1,280,000	0·85-1·05	1	16
Kinsui, Taiwan ...	1,500,000	0·62	0·3	3
Total	10,226,000			1,282

Types of Natural Gas

The majority of natural gas produced by the Nippon Oil Company belongs either to the pure hydro-carbon type, or to that having a comparatively large percentage of nitrogen and therefore inferior in heat generation. The former includes the gas from Nishiyama, Takamachi, Hokkaido and Kinsui, which gives approximately 1,000 B.Th.U. per cu. ft., while the latter from Niitsu and Akita gives 800-900 B.Th.U. The natural gas from Shukkoko, Taiwan, belongs to the carbonic acid gas type, containing more than 30 per cent. of carbonic acid gas. It gives only 700-780 B.Th.U., per cu. ft. and is 30 per cent. inferior in fuel value compared with the better quality gas. The average value of natural gas as fuel on the field is estimated to be Y8.00 for 10,000 cu. ft., the total fuel value thus being Y8,000 per day. With regard to gasoline content, Ishikari natural gas in Hokkaido gives the highest yields, the better grade gas of Nishiyama being next. The natural gas from Takamachi and Kinsui is extracted from high-pressure gas wells.

Gasoline Extraction Apparatus

The first compression apparatus imported from U.S.A. was erected at Nishiyama Oil Field, in October, 1914, and since then many plants have been erected in various places.

The first absorption plant was one of 15,000,000 cu. ft. capacity and was erected in July, 1914, to control the 30,000,000 cu. ft. of gas gushing from No. 5 well at Kinsui, Taiwan, and as the result was satisfactory, many more plants have been erected.

COMPRESSION PLANTS

Location of Plant.	Compressor.		Motor.	
	Daily Capacity. cu. ft.	Number.	Horse Power.	Number.
Nishiyama	3,000,000	6	750	6
Ohmo	300,000	1	80	1
Yuri	900,000	3	275	3
Kurokawa	1,000,000	2	200	2
Hokkaido	300,000	1	80	1
Shukkoko	500,000	1	150	1
Total	6,000,000	14	1,535	14

ABSORPTION PLANTS

Location of Plant.	Size of Absorber.	Number.	Maximum Pressure. lb. per sq. ft.	Maximum daily capacity. cu. ft.
Nishiyama ...	4′ 6″ × 30″	2	100	8,000,000
For blending ...	3′ 0″ × 30″	2	200	3,000,000
Takamachi ...	4′ 6″ × 30″	2	100	8,000,000
Shukkoko ...	4′ 6″ × 30″	1	100	4,000,000
		5	200	
Kinsui	3′ 0″ × 30″	6	100	15,000,000
Total ...		18		38,000,000

REFINING METHODS IN JAPAN

The first oil refining in Japan was carried out fifty-five years ago when kerosene was the sole valuable product to be derived from crude petroleum. It was distilled in cast-iron vertical stills of about twenty-five barrels capacity, the remaining oil being thrown away. Since then a demand for gasoline, neutral oils, lubricating oils and many other products has appeared. New methods of manufacturing from crude oil the various products for which a market demand was felt, were introduced, mostly from America, especially

at the period of the industrial expansion of Japan. During and after the Great War, the oil refining industry experienced phenomenal development, and now refining methods in Japan are not only able to compete with foreign countries, but can show many improvements designed to meet local conditions.

The refining industry, one of the most important in Japan, deals not only with Japanese crude oil but also with imported oil from America and the South Sea Islands.

The following is an outline of refining methods now in use:—

Methods of Distillation

The distillation of crude oil is carried out mainly by the continuous system, but in some rare cases the batch system is also adopted. The stills are of 100 to 600 barrels capacity, and in the case of continuous distillation six to ten stills comprise one unit. The capacity of one battery is 40,000 to 120,000 barrels a month, and although its scale is not large compared with those in America, the point in favour of the Japanese still is the elaboration of design.

Molten pitch, solid pitch, acid sludge and sometimes heavy oil are used as fuel for distillation purposes. Solid pitch is very difficult to burn as fuel but, by the use of special apparatus, it is gradually melted by the heat of its own furnace, atomised by steam and burned with little smoke, as is the case with heavy oil. Previously, heavy oil and gas were considered to be the only suitable fuels for continuous distillation, the fire regulation of which was very difficult. Recently, however, refining technique has made a decided advance, and acid sludge has become an important fuel which can be burned satisfactorily. The efficient utilisation of fuel is the result of an immense amount of labour on the part of technicians, and the following equipment and apparatus, amongst others, have been designed to this end:—

(*a*) An apparatus acting both as dephlegmator and heat exchanger in order to heat crude oil by means of the oil vapour from the still.

(*b*) A boiler of small size is attached to the flue to absorb the remaining heat.

(*c*) Residuum oil to be re-run, flows directly into the still without any loss of heat, and before the oil is sent to storage, a heat exchanger is utilised to heat the charging stock.

The impossiblity of obtaining a "narrow cut" fraction has hitherto been the objection to the continuous method, but recently, using the

apparatus which serves both as dephlegmator and heat exchanger, the oil vapour from the still is divided into four cuts, and with the special automatic re-run equipment, the degree of fractionation is the highest obtained in the world.

The uncondensable gas from the still is washed with chemicals to neutralise its corrosive compounds, and then treated similarly to natural gas in order to extract gasoline by condensation and absorption methods.

Cracking Processes

Methods of making gasoline by the cracking of heavy oil have been studied for many years, and the first cracking operation of industrial size was made in 1912, using heavy oil and fish oil as raw materials. Since then, the economical value and quality of cracked gasoline have been gradually appreciated and its demand has been greatly increased.

The Dubbs, Cross, and Jenkins cracking processes were introduced into Japan in this order, and now two Dubbs units and one Cross unit are operated by the Nippon Oil Company, one Jenkins unit being worked by the Ogura Oil Company. The total output of cracked gasoline is now 300,000 barrels a year.

(a) The Dubbs Cracking Process

The Dubbs process was invented for the purpose of cracking heavy oil as well as gas oil. Two Dubbs plants are now working in Japan; their capacity is 750 barrels a day each, the first being installed in 1924 at the Tsurumi Refinery of the Nippon Oil Company. The materials used are mainly California gas oil and topped crude oil, at an operating pressure of 140 lb. per sq. in., and a temperature of 480°C., one cycle occupying four days. The pressure distillate produced is washed with sulphuric acid and doctor solution and redistilled, using steam. The yield of cracked gasoline is about 35 per cent. by volume of the charge, its quality being better than that of U.S. New Navy gasoline.

The coke, a by-product of this cracking system, is useful as domestic fuel.

(b) The Cross Cracking Process

This process produces gasoline from kerosene and neutral oil by cracking and synthesising under high pressure and temperature. At present one unit of this process is working and was installed in 1926 at the Niigata Refinery of the Nippon Oil Company, its cracking capacity being 1,000 barrels a day. The charging stock is mainly

gas oil from the Niitsu and California crude oils, with an operating pressure of 700 lb. per sq. in., a temperature of 480°C., and a complete cycle of from five to eight days. The crude gasoline produced by the plant is washed with sulphuric acid and, after neutralisation, is re-distilled using steam. The gasoline made by this process is superior to that of the Dubbs process, owing to the superiority of the charging stock.

(c) The Jenkins Process

This process was also introduced from America, and one unit was installed in 1926 at the Tokio Refinery of the Ogura Oil Company. It is the only Jenkins plant now working in Japan and has a daily capacity of 500 barrels. The raw material is mainly gas-oil from Californian crude oil, an operating pressure of 120 lb. per sq. in. being employed.

The cracked gasolines made by these processes are now widely used in Japan as the "Knoxless-pullsmore" motor fuel, and recently they have been used as an aeronautic motor fuel, in spite of their unpleasant odour.

Vacuum Distillation

Steam is used during distillation in order to prevent decomposition of the crude oil, but to make its effect complete, distillation at lower pressure than the atmospheric pressure is essential. For this purpose, many attempts have been made to discover the optimum degree of pressure reduction and its effect.

However, no plant of industrial size was constructed until 1926, when the Schultze Vacuum Distillation process was first introduced into Japan, and since then six units of this process have been installed and are dealing with from 22,000 to 33,000 barrels of crude oil per month.

The raw materials are Niitsu and California crude oils, the process being carried out as follows:—

Firstly, the crude oil is heated in the usual type of still, whereby water is completely removed. The hot crude oil is next transferred to the vacuum still and heated gradually, using heavy oil or gas as fuel. At the same time, a vacuum pump is used to keep the still pressure at between 24·0 mm. and 1·0 mm. of mercury, the distillation being carried out at a temperature not exceeding 320°C.

As the product produced by this process is good in colour, high in

flash point and low in freezing point, much of it requires no chemical treatment, but if it be re-distilled in the same apparatus, even better lubricants can be obtained. Owing to the excellent results given by the vacuum distillation process, many refineries have attempted to follow this example, and it is believed that in the near future almost all the crude oil will be treated by this method.

Treating, Bleaching, and Filtering Processes

With the exception of certain types of lubricating oil, all distilled products are treated with chemicals, and then receive bleaching treatment. These treatments are known as "washing" in the technology now current in the refining industry. Washing is carried out by the batch system, the oil being treated with sulphuric acid and then neutralised with caustic soda. It is a common method of treatment, but it varies in detail, according to the type of oil, and the degree of refining required.

Naturally, the fundamental principles of refining have been introduced from foreign advanced countries, but many details peculiar to the Japanese refining industry have been developed to meet special conditions.

For example, it has been found that fuming sulphuric acid can be used successfully to give 150 to 300 per cent. more effect than by the use of concentrated sulphuric acid.

Again, Japanese acid clay in powder form is used satisfactorily for the decolourisation of kerosene and neutral oils, as well as for heavy lubricating oils. Moreover, as the acid clay is quite effective in powder form, it is only used in granules in some exceptional cases. All products except gasoline are passed through the filter press after receiving chemical treatment. Acid tar is decomposed by steam, regenerated, and used over again. Naphthenic acid is recovered from waste soda, while the waste liquor from the water washing of acid or soda treated oils is neutralised and bleached before being discharged as harmless effluent.

DEMAND AND SUPPLY OF PETROLEUM IN JAPAN

The increasing demand for petroleum and its products is apparent throughout the world, and particularly in Japan, where petroleum is and will be required in ever increasing quantities. This tendency is shown in the following table:—

Unit: case of 10 U.S. gallons.

		1922	1923	1924	1925	1926	1927
Gasoline.	All Japan, including Korea & Formosa	2,025,000	2,157,000	3,326,000	3,912,000	5,257,000	6,301,000
	Japan proper.	1,905,000	2,034,000	3,135,000	3,682,000	4,992,000	6,009,000
Kerosene.	All Japan.	5,158,000	5,159,000	5,102,000	5,392,000	4,641,000	5,410,000
	Japan proper.	4,170,000	3,850,000	3,830,000	3,803,000	3,464,000	3,886,000
Neutral oil.	All Japan.	3,911,000	3,783,000	4,658,000	5,041,000	5,573,000	5,070,000
	Japan proper.	3,797,000	3,634,000	4,489,000	4,816,000	5,326,000	4,781,000
Fuel oil.	All Japan.	1,525,000	2,969,000	3,934,000	5,114,000	6,077,000	8,656,000
	Japan proper	1,497,000	2,930,000	3,865,000	5,005,000	5,403,000	7,946,000
Lubricating oil.	All Japan.	2,844,000	3,668,000	4,336,000	3,518,000	3,892,000	4,236,000
	Japan proper.	2,522,000	3,405,000	4,051,000	3,233,000	3,542,000	3,805,000
Total.	All Japan.	15,462,000	17,736,000	21,357,000	22,978,000	25,439,000	29,673,000
	Japan. proper.	13,891,000	15,852,000	19,369,000	20,538,000	22,727,000	26,427,000

For several years the demand for petroleum has increased by 10 per cent. yearly, the estimated figures for 1927 compared with those of 1922 being as follows:—

Gasoline increased by about 200 per cent. (*i.e.*, trebled).
Kerosene no change.
Neutral oil increased by about 20 to 30 per cent.
Fuel oil increased by about 400 to 500 per cent.
Lubricating oil increased by about 50 per cent.

Owing to the increased use of electricity for illumination purposes, the demand for kerosene for this purpose has decreased, but on the other hand, its use as fuel for agricultural machinery, furnaces and ovens has increased, and by striking a balance, kerosene consumption shows neither increase nor decrease. The reason why the increase in the demand for neutral oil is not so remarkable is

that there is a tendency amongst fishing motor-boats to change to fuel oil burning. Under these circumstances, the demand for this oil increased rapidly year by year until 1926, after which it decreased by about 10 per cent. The remarkable increase in the demand for fuel oil in 1927 is the result of the decrease of the demand for neutral oil.

Subdivided according to the consumer, oil is consumed yearly as follows:—

Gasoline:—		10 gall. cases.
By automobiles (100 cases for each car)	about	5,000,000
By aeroplanes	,,	500,000
By industrial and other uses	,,	500,000
Total about		6,000,000

Kerosene:—		10 gall. cases.	
Illuminating oil	about	1,000,000	(Korea)
Illuminating oil	,,	2,000,000	(Others)
Heating oil	,,	1,300,000	
Power oil	,,	700,000	
Total about		5,000,000	

Neutral Oil:—		10 gall. cases.
By fishing-boat	about	4,000,000
,, others	,,	1,000,000
Total about		5,000,000

Fuel Oil:—		10 gall. cases.
By fishing-boat	about	3,000,000
,, others	,,	5,000,000
Total about		8,000,000

Lubricating Oil:—
About 4,000,000 cases, particulars not available.

The above figures do not represent the total consumption of petroleum in Japan, as they do not include consumption by the navy and foreign route vessels, and if these demands be added to the total, Japanese consumption will be twice as large as the above figure.

With regard to production in Japan, it is to be greatly regretted that it is too small to meet these vast requirements.

To begin with, crude oil production in Japan is as under:—

	Unit Koku of 1.136 U.S. barrel.
1916	2,610,000
1921	1,968,000
1922	1,811,000
1923	1,590,000
1924	1,599,000
1925	1,660,000
1926	1,577,000
1927	1,530,000

For refined oils, production figures are as follows:—

	Gasoline.	Kerosene	Neutral oil.	Fuel oil.	Lubricating oil.	Total.
1922	653,000	754,000	2,974,000	588,000	1,382,000	6,351,000
1923	664,000	644,000	2,719,000	717,000	1,428,000	6,172,000
1924	612,000	750,000	2,539,000	597,000	1,519,000	6,017,000
1925	831,000	752,000	2,476,000	589,000	1,400,000	6,048,000
1926	1,153,000	545,000	2,560,000	585,000	1,380,000	6,223,000
1927	1,391,000	571,000	2,292,000	506,000	1,486,000	6,246,000

In other words, home production is sufficient for only one quarter of the total demand, even excluding the needs of the navy and of foreign route vessels. The remaining three-quarters is supplied by imported oil, either as crude or as refined products.

Summarising, of the total requirements excluding the needs of the navy and of trans-oceanic vessels, one quarter is supplied from home sources, one quarter is derived from imported crude oil which is refined in Japan, while the remaining half is supplied in the form of imported refined products.

RÉSUMÉ

Les couches pétrolifères du Japon appartiennent presque toutes à l'époque tertiaire. Les principaux gisements sont ceux des préfectures de Yamagata et de Niigata, sur la côte nord-ouest de Honshu, ainsi que ceux des îles de Sakhaline et de Taiwan.

Des 3416 puits de pétrole de la Compagnie Japonaise des Pétroles, le 30 septembre 1927, 418 étaient exploités au procédé de forage dit "Kazusa-bori." Ce procédé particulier au Japon est expliqué en détail dans le texte anglais. Le forage au câble en opération sur 2090 puits fut introduit au Japon en 1894. Le forage par rotation fut introduit en 1912. Ce procédé permet un forage très profond et on s'en sert sur 864 puits.

La production de gaz naturel des 1282 puits de la Compagnie Japonaise des Pétroles est de 10.226.000 pieds cubes par jour. La gravité varie de 0,6 à 0,9, l'essence contenue de 0 à 6 gallons impériaux par 1000 pieds cubes. La plupart des gaz naturels sont des gaz d'hydrocarbure pur d'une puissance calorifique de 800 à 1000 B.T.U. par pied cube. Le reste sont des gaz d'acide carbonique d'une puissance calorifique de 700 à 780 B.T.U. par pied cube.

En général on se sert au Japon de la distillation en continu, mais aussi du procédé de la fournée. Le craquage se fait d'après les procédés Dubbs, Cross ou Jenkins.

En 1916, la production de pétrole brut était de 2.610.000 kokus de 1,136 barils américains; elle n'était plus que de 1.968.000 kokus en 1921 et de 1.530.000 en 1927. La consommation de pétrole brut et de ses dérivés est considérable et plus de la moitié doit être importée de l'étranger.

GENERAL REPORT ON SECTION E

THE OIL INDUSTRY
ECONOMIC AND GENERAL CONSIDERATIONS

J. KEWLEY

This general report deals with two papers only, *viz.*,

(1) The Economics of the Oil Industry,

(2) The Oil Industry in Japan.

The paper by Professor M. Defay on "The Present Position of Heavy Oil for Motor Traction," may also be referred to in this connection.

The first of these papers deals with the fluctuations in the gasoline market and their causes.

(In this report the words "gasoline" and "motor spirit" are interchangeable.)

The major problem of the oil industry since the war has undoubtedly been that of producing sufficient fuel for the ever-growing automobile industry. The demand for gasoline for the domestic and export markets of the U.S.A. in 1927 was about nine times that for 1914. In Japan the demand for gasoline has trebled itself during the last six years.

This enormous increase in the demand has been so successfully met that the price of gasoline shows the least increase since 1913 of any of the commodities in everyday use, in spite of the increased cost of drilling and refining.

This result has been achieved in three ways:—

1. By increasing the production of crude oil.
2. By increasing the yield of gasoline obtained from the crude, by cracking, and
3. By development of the natural gas gasoline industry.

If methods of increasing the yield of gasoline from the crude had

not been devised, then more than double the present production of crude oil would be necessary to meet the present demand for gasoline. As the demand for the other products derived from crude oil did not increase to the same extent, the price of gasoline would have soared. In other words, the increased efficiency of the refining processes has greatly cheapened the price of gasoline. The extent to which these methods have assisted is evidenced by the facts that since 1916, the production of natural gas gasoline has increased by 1,473 per cent. and of cracked gasoline by 1,359 per cent.

Japan, which is faced by a steady decrease in her crude oil production, early realised the value of the new methods, having erected her first natural gas gasoline plant in 1914 and her first cracking plant as early as 1912. By so doing, she more than doubled the yield of gasoline from the crude oil in six years.

The fluctuations in the price of gasoline during the last ten years have broadly followed fluctuations in the price of the raw material. The supply of crude must fluctuate because of the element of chance in the business of oil production and the intensive competition displayed in the majority of American oil fields.

The chance discovery of prolific sands in the Seminole area is quoted as an example of a case where an orgy of competitive drilling broke the market in crude oil and sent prices down by more than half.

An analysis is given of the costs of crude oil production and the great variation in the expenses of drilling from field to field is pointed out. This is well illustrated by the case of Japan, where the primitive methods of drilling by hand sunk wells coexist with modern methods. Drilling in the U.S.A. has certainly become more expensive each year, due undoubtedly to a great extent to the greater depths to which wells are drilled. The average cost of drilling a well in U.S.A. is given as $18,725 in 1927, as compared with $4,765 in 1913. Estimates are given for the average cost of producing a barrel of crude oil in America. Of such costs only 22½ per cent. are due to direct oil raising expenses and only 13·2 per cent. due to dry holes and abandoned wells.

As the price of crude oil is generally posted in America for a number of different districts it obviously cannot bear any exact relation to the actual costs of production. Nor can the price of gasoline bear any systematic relation to the cost of manufacture. The average

barrel of crude oil may be taken to yield 27 per cent. of gasoline, 10 per cent. of kerosene, 46 per cent. of fuel and gas oils and 7 per cent. of other products. If this average composition of crude oil is considered and if the costs of manufacturing these products are taken at those proportions of the total price realised, represented by their proportionate yields from the crude oil, it will be found that some of the products would be selling at a dead loss. Gasoline as a rule must carry a price which will return a much greater proportion of the total receipts than is represented by its proportionate production from the crude oil. This is a natural result of the relations between supply and demand of the various products from the crude oil. The result is that it is necessary to pay a relatively higher price for gasoline in order to make (1) the producer of crude oil supply the refineries with so much crude, and (2) the refineries erect the necessary cracking and natural gasoline plants, that the demand for gasoline can be met, this demand being the primary basis for the demand for crude oil. This is the situation which controls the American oil market at the present time.

The author is of the opinion that the supply of gasoline from other sources is not likely to influence the price of petroleum gasoline for a considerable time.

The second paper gives a résumé of the oil industry in Japan, pointing out the distribution of the oilfields and their geology, the drilling and producing methods in use and the refining methods employed, as well as the development of the natural gasoline and cracking industries to which reference has already been made. Japan has certainly been to the fore in adopting new methods as soon as ever they were available.

DISCUSSION

TUESDAY, SEPTEMBER 25 (MORNING)

Section E

THE OIL INDUSTRY
ECONOMIC AND GENERAL CONSIDERATIONS

Chairman: SIR ROBERT WALEY COHEN, K.B.E.

THE CHAIRMAN, opening the proceedings, said it was a great pleasure to see so many friends from all parts of the world assembled for the purpose of the discussions. Provision was made in the programme, he said, for the Chairman's introductory remarks, and it had been suggested that he might talk about the political aspect of the industry. He felt, however, that as the oil industry had been struggling for years to free itself from political contagion, this was the last thing the Section would desire to deal with. Therefore, he proposed to proceed immediately to the business of the Section.

MR. KEWLEY (Vice-Chairman and General Reporter) then presented his General Report.

MR. J. KEWLEY (Vice-Chairman, Great Britain), who opened the discussion on the papers presented to Section E, drew attention also to a paper by Professor J. Elin, of Russia, which was presented later, in Section F, in which it was pointed out that the further development of the natural gas industry in Russia would be of special value owing to the fact that the Russian crude oils were so deficient in the low-boiling fractions that the whole of the distillate, with sufficiently low endpoint, could not be used for making gasoline. This applied, of course, to several other types of crude oil in various fields. Supplementing Mr. Davenport's paper, he said that in addition to the three methods mentioned for meeting the ever-increasing demand for motor fuels, several other factors should be considered. The first was the development of engine design. This was going on in two directions: (1) that of increasing the efficiencies of engines which ran on existing volatile fuels, thus making better use of the available gasoline, and (2) that of developing the heavy oil engine so that it could, partly at any rate, do the work now done by gasoline engines, thus making much larger supplies of fuel available. Another factor was the recent development in the direction of altering the quality of the gasoline manufactured so as to permit of its being used in engines of higher efficiency. One of the limits imposed on the development of gasoline engines in the direction of higher efficiencies was that due to the tendency to detonate, exhibited by many types of gasoline. Efforts were, therefore, being

made to improve the anti-knock values of gasoline fuels. So far as could be seen at present, this could be effected in two ways: (1) by the development of high-temperature vapour phase cracking processes, which produced hydrocarbons of high anti-knock value, and (2) by the addition of anti-knock dopes to existing fuels. The former method would thus have a double influence on the gasoline price, in that it would not only increase the quantity, but also improve the quality, of gasoline supplies. The second method was limited in its application. The extension of the use of the heavy oil engine and the development of cracking processes seemed to him the most promising directions from which to expect cheaper gasoline. He did not agree with Professor Defay, who regarded the cracking process as a transitory solution; nor did he agree that cracked gasoline was of poor quality.

As the result of such developments, a large proportion of the crude oil supplies would become available for motor traction in its broadest sense, and thus permit of the reserving of the more volatile fuels for special purposes.

The cracking process seemed also to offer a hopeful solution of the problem of utilising the oils which would be available in the distant future as a result of the distillation treatment of shales, coals and the like. This raised the question of the future supplies of crude petroleum. Incidentally, he had made a calculation of the total volume of crude oil which had been extracted from the earth. When expressed in millions of barrels it seemed a large amount, but it did not appear so large when expressed in cubic measurements. The total world production of crude oil since 1859 amounted to only 0·8 cubic mile, which represented only a very small percentage of the potentialities of the petroliferous areas of the world.

There was still another direction in which to expect developments which would cheapen the price of petroleum fuels. It had been pointed out by Mr. Davenport that gasoline had to bear a large share of the costs of working up the crude oil. This share could be reduced by increasing the number and importance of the products derived from petroleum. The great expansion of the petroleum asphalt industry during the last few years afforded a good example of this effect. The quantity of asphalt made in the United States in 1919 was $1\frac{1}{4}$ million tons, and in 1926 the quantity made there was $3\frac{1}{2}$ million tons. This particular development was of especial interest, as good roads meant reduced fuel consumption. It was indeed fortunate that the industry which by its development produced cheap fuels produced also the necessary concomitants, lubricating oil and road surfacing materials. It also produced carbon black, the incorporation of which into rubber had so wonderfully improved motor tyres during the last ten years.

There were, however, indications of great developments pending in the direction of the manufacture from petroleum of many products which, though not fuel, would have their effect in reducing fuel prices. The vast quantities of natural gas which were now wasted, or at best had only fuel value, would in the near future undoubtedly

find new applications as basic materials for the manufacture of valuable products, such as formaldehyde, alcohols, and so forth. The gases from the cracking process would furnish alcohols, glycols and a multitude of products which would readily be made from the reactive unsaturated hydrocarbons. These factors might reasonably be expected to play a part in keeping down the price of those derivatives in which the Conference was particularly interested.

Dr. G. Egloff (U.S.A.) said that the total quantity of crude oil produced in the world since the foundation of the industry was about 16 billion (sixteen thousand million) barrels, and Mr. Kewley's statement that that quantity would occupy a space of 0·8 cubic mile showed how insignificant it was in relation to the total supplies available. Geologists had indicated that in the United States there were something like 1,100 million acres of land containing oil, and that we were at present producing oil from only about two million acres. Recently a commencement had been made to develop a vast area of oil-bearing lands in West Texas, the potentialities of which staggered the imagination. From each of ten producing wells there had been obtained an average of 17,600 barrels per day, at a depth of 1,100 ft. If all the wells which had been prorated in the West Texas field were permitted to flow to their full capacity, they would produce over $3\frac{1}{2}$ million barrels of crude oil per day, which was more than the whole world could absorb. When one considered the vast potential supplies of oil available, not only in the United States, but in Mexico, and the South American States, such as Colombia, Peru, and Venezuela, as well as in Russia and other parts of the world, it would be appreciated that there existed potential supplies in excess of any reasonable demand for many years to come. Dealing with the consumption of motor spirit, he said that in Great Britain there was one motor car for every thirty-seven persons, in France one for every forty persons, in Germany one for every 148 persons, and in Italy one for every 250 persons. He saw no reason why, with reasonable legislation, the reduction of taxation on motor cars and gasoline, the reduction of the price of motor cars, and the widening of roads, there should not be 24 million motor cars—or one to every twenty persons—in Europe ten years hence. It might be asked where the gasoline was to come from but he believed there were sufficient oil supplies in sight to last at least 100 years. In his opinion the price of gasoline in the United States had been very low, in the past three years at least, and the quality had improved in the last seven years. The average end-point of the gasoline in the United States at present was about 410°F., which meant that the refiners were now extracting about 12 per cent. less gasoline per barrel of crude oil than was the case when the endpoint was from 437 to 450°F. The suggestion that the endpoint should be reduced and so less gasoline extracted was made by a large group in the United States in order that more crude oil should be used. The price of gasoline at refineries for two years had ranged from $5\frac{3}{4}$ to 7 cents per gallon, and it was now about $9\frac{1}{2}$ cents per gallon. The refineries in the United States were at

their wits' ends to open up new fields for their products, and one direction in which they had been working was to push the household use of fuel oil or gas oil, particularly gas oil. Five years ago there were about 100,000 burners used in households and office buildings in the United States; the number of burners used there at present for household heating purposes had increased to 1,100,000, and the consumption of gas oil for such purposes had increased to something like 70 million barrels per annum. That was a valuable outlet for the products of the refiners. Discussing other outlets for the products of the refineries, he said that in Germany they were oxidising paraffin wax on a commercial scale, in order to produce products such as phenolic compounds suitable for emulsion making, and converting asphalt into an emulsion for spreading on to the roads. In the United States during the last five years they had created practically a new industry by producing roofing paper from wood pulp mixed with asphalt on a regular paper-making machine. For some of the synthetic products of petroleum, such as isopropyl alcohol, there was a demand, but it was not very large, and many technicians were working on the problem of synthesising rubber from the gases produced in cracking. On the assumption of 1 per cent. butadyene in the cracking gases, he had calculated that there could be produced from the cracking gases in the United States—which amounted to something like 200 billion cu. ft. per annum—something like 396 million lb. of a rubber-like material per annum.

The Chairman, who prefaced his remarks by saying that he intended to be provocative, said he had heard such loose expressions as "better quality petrol," but he did not know who would dare to say that one petrol was of better quality than another. It seemed to him that the experts had a long way to go before they could tell us that any one petrol was really going ultimately to be a better source of power than another. The elimination of high boiling point fractions had been spoken of as though it constituted an improvement in quality. He was not at all sure, however, that the fractions eliminated were not some of the most valuable, and that the technical men had not yet gone far enough to be able to show how to use them to advantage. With regard to the economics of the industry, he said that perhaps Mr. Kewley was a little optimistic in thinking that the development of Diesel engines would necessarily make gasoline cheaper. As one interested in making the oil industry serve humanity more and more, he hoped to see the time when the development of the Diesel engine would give rise to a spirit of competition between the user of the Diesel engine and the user of the automobile—the Diesel engine man trying all the time to keep the fine heavy fractions in the part which he wanted, and paying increasingly higher prices for them because he could put them to better advantage, and the automobile man trying to put those fractions into the cracking still. He did not know which of those two competitive elements the World Power Conference would like to see succeed, but his feeling was that in this serious age the Diesel engine user should succeed and should capture a large proportion

of the total crude oil production. In that sense we might find ourselves unable or unwilling to waste it in the cracking stills, and might put it straight into a very efficient internal combustion engine. There had been references recently to a Diesel engine which was going to be used for automobiles. It had been hailed as though it were something that was going to make travelling on the road much cheaper, because Diesel oil was at the moment cheaper than petrol, but it was well to reflect that, as was stated in one of the papers under discussion, the so-called values of petroleum products were purely functions of supply and demand. If, as the result of the activities of the experts in the petroleum industry, the heavy fraction became more in demand, it would not be long before that heavy fraction had to protect itself by asking the same price for its use as for the use of the lighter fractions. It was very easy to realise the cost of the light fraction as being almost exactly the same as that of the heavy fraction. They all came out of the earth together, and we were thrown back on the final test of the real value of each as a producer of power. This scientific assembly could afford to neglect fortuitous passing currents of differences in value such as those which existed to-day between petrol and heavy oils.

Mr. W. A. Whatmough (Great Britain), who had been studying the conditions under which petrol could be used to the best advantage, said there was no question that in engine practice the first and foremost quality desirable in a petrol was the so-called volatility, and that was best represented by mean volatility, which could be measured in many ways. Some preferred to calculate it from what was called in this country Engler's distillation curve, and in America the A.S.T.M. distillation, or it was possible to determine the mean volatility by boiling the petrol continuously under conditions in which eventually it attained a mean boiling point. In actual practice that mean volatility, either calculated or determined, had a definite relationship to petrol vaporisation in the induction pipe, and, provided that a corresponding air temperature was used, excellent distribution of combustible mixture, which was the first step to combustion and power production, followed naturally. The No. 1 petrol in this country would give perfect distribution with an air intake temperature round about 110 or 120°F. By paying another 3d. or 4d. per gallon for aviation spirit, one was able to obtain similar distribution with a temperature reduced by 10 or 15°F., but those who wished to save money, and to obtain more value for money, could use the commercial petrol, and the induction temperature needed to be raised only about 10°F. above that required when No. 1 spirit was used. He held no brief for the petrol companies, but he felt compelled to say that the big companies did provide very good and consistent supplies of No. 1 petrol in this country. The basis of engine design and carburation depended upon the continued supply of that good quality petrol. There were a number of distillates offered as petrol, but which were by no means so consistent in quality as were those supplied by the big

companies. From the point of view both of the user and the engine designer it was exceedingly important that there should be some recognised standard for No. 1 petrol, because that was the grade which sold most and controlled the quality of petrol on the market. With regard to the production of the so-called anti-knock petrol, he said that was really an endeavour on the part of petrol producers to overcome to a certain extent bad engine design. On the other hand, there was no disadvantage in using a petrol of high anti-knock quality. The idea that anti-knock fuels were necessary to stop engine detonation had been greatly exaggerated, and in his opinion fuel testing was nothing like so accurate from an anti-knock point of view as it was from a distillation point of view.

This concluded the discussion on Section E.

SECTION F

COMPOSITION, CLASSIFICATION, PREPARATION, STORAGE AND HANDLING OF LIQUID FUELS

F1 THE CHARACTERISTICS OF MOTOR SPIRIT.

F2 THE AVAILABILITY OF THE ALBERTA BITUMINOUS SANDS FOR PRODUCTION OF FUEL OIL.

F3 PROPERTIES REQUIRED OF LIQUID FUELS FOR USE IN AUTOMOBILE AND AIRCRAFT ENGINES, AND HOW THE OIL INDUSTRY MEETS THESE REQUIREMENTS.

F4 RECENT DEVELOPMENTS IN THE DISTILLATION OF PETROLEUM.

F5 CHEMICAL REACTIONS INVOLVED IN THE REFINING OF PETROLEUM.

F6 THE COMPOSITION AND CHEMICAL PROPERTIES OF RUSSIAN OILS.

F7 INVESTIGATIONS IN DISTILLING PROCESSES OF SWEDISH OIL SHALES.

F8 RECENT ADVANCES IN CRACKING.

F10 THE TECHNICAL ASPECTS OF THE STORAGE, HANDLING AND TRANSMISSION OF LIQUID FUELS BY THE USER.

F11 SHALE AND THE PRODUCTION OF OIL FROM SHALE.

F12 THE CRACKING PROCESS—A UNIVERSAL SOURCE OF MOTOR FUEL

F13 CHEMICAL COMPOSITION OF POLISH NATURAL GASES AND THE DETERMINATION OF THEIR CALORIFIC VALUE.

THE NUMBERS ARE THOSE GIVEN TO EACH PAPER
FOR USE AT THE FUEL CONFERENCE

DIE KENNZEICHNUNG VON MOTORBENZIN

(THE CHARACTERISTICS OF MOTOR SPIRIT)

GESELLSCHAFT FÜR WÄRMEWIRTSCHAFT, WIEN

*Paper No. F*1

CONTENTS

INTRODUCTORY—SPECIFIC GRAVITY—BOILING RANGES—METHODS OF CHARACTERISATION—FIXED TOLERANCES—SPECIFICATIONS

RÉSUMÉ

Benzin besteht aus leichten und schweren Kohlenwasserstoffverbindungen, die bei verschiedenen Temperaturen verdampfen. Siedebeginn der leichten und Siedeendpunkt der schweren Verbindungen sind ebenso wenig an bestimmte Temperaturgrenzen gebunden, wie die Anteile, die bei den verschiedenen Temperaturen übergehen sollen. Daraus ergibt sich eine unübersehbare Fülle von Zusammensetzungen, die die Eigenschaften des Benzins als Motorbetriebsstoff wesentlich beeinflussen. Leistung und Betriebsstoffverbrauch stehen bei einer bestimmten Motoreinstellung in unmittelbarem Zusammenhang mit den Eigenschaften des Benzins; es ist deshalb begreiflich, dass Richtlinein für die Kennzeichnung der verschiedenen Benzinsorten dort schwer vermisst werden, wo die Betriebsführung auf die günstigste Brennstoffausnutzung Wert legt.

Schon vor dem Kriege, wo der Kraftwagen noch lange nicht die Bedeutung als Nutzfahrzeug hatte, wie es jetzt der Fall ist, war der *Oesterreichische Automobiltechnische Verein* bemüht, die *handelsübliche Kennzeichnung nach dem spezifischen Gewicht auszuschalten.* Im alten Oesterreich-Ungarn wurden die Beratungen und Vorschläge von der Tatsache beherrscht, dass das auf den Markt gebrachte Benzin fast ausschliesslich galizischen Ursprunges war und dass deshalb unter gewissen Voraussetzungen ein *Einheitsbenzin* für den Motorbetrieb erzeugt werden könne. Nach dem Zerfall Oesterreich-Ungarns haben sich die Verhältnisse auf dem inländischen Benzinmarkt vollständig verändert, sie haben in

gewisser Hinsicht eine ähnliche Gestalt gewonnen, wie in anderen Staaten, die auf ausländischen Bezug angewiesen sind.

Die Verarmung Europas hat überall den Gedanken ausgelöst, die Wirtschaftlichkeit der Betriebe im allgemeinen zu heben und im besonderen die Wärmewirtschaft zu pflegen. In Oesterreich war die Trägerin dieses Gedankens die im Rahmen der technischen Abteilung des Hauptverbandes der Industrie gegründete *Gesellschaft für Wärmewirtschaft*, deren *Arbeitsausschuss für flüssige Brennstoffe* die Frage behandelte, wie *Motorbenzin zu kennzeichnen ist.* Welche Eigenschaften Motorbenzin haben soll, wurde nur insofern erörtert, als sie zur Kennzeichnung unerlässlich sind. Der Unterausschuss hatte somit die Aufgabe, die vor dem Kriege vom Oesterreichischen Automobiltechnischen Verein eingeleiteten Arbeiten fortzuführen, und es war selbstverständlich, dass zum grossen Teile auch dieselben Personen die Arbeiten weiterführten.

Die am Schlusse des Artikels wiedergegebenen *"Richtlinien,"* die nunmehr vorliegen, sind das Ergebnis zahlreicher Beratungen und Versuche; sie stellen eine Vereinbarung der Benzinerzeuger und Händler mit den Benzinverbrauchern dar.

Spezifisches Gewicht.—Im Handel und in den Zolltarifen wird allgemein das spezifische Gewicht (Dichte) vornehmlich oder ausschliesslich als kennzeichnende Eigenschaft verwendet, wiewohl allgemein erkannt und anerkannt ist, dass das *spezifische Gewicht für die Beurteilung des Benzins keine oder nur eine höchst untergeordnete Bedeutung* hat.

Ursprünglich war Benzin ein Nebenerzeugnis der Erdölverarbeitung; es konnten deshalb auch Sonderwünsche der Verbraucher weitgehend berücksichtigt werden. Verlangt wurden gewöhnlich enge Siedegrenzen und da innerhalb solcher bei demselben Ursprungsstoff das spezifische Gewicht nur geringfügig schwankte, war es auch zulässig, Benzin durch das spezifische Gewicht zu kennzeichnen. Ueberdies hat die Internationale Petroleumkommission auf ihrer Tagung in Wien[1] für die Handelsüblichkeit ausgesprochen, dass innerhalb der Siedegrenzen die Hauptmenge (z.B. 75v.H. und mehr) überzugehen habe; dadurch sind auch dem spezifischen Gewicht gewisse enge Grenzen gesetzt.

Mit der Entwicklung des Kraftfahrwesens steigerte sich die Nachfrage nach Benzin als Betriebsstoff in fast ungeahnter Weise, so dass die Benzinerzeuger bei der mehr oder minder geringen Ausbeute aus dem Erdöl gezwungen waren, die Siedegrenzen immer weiter

[1]Hauptversammlung der Internationalen Petroleumkommission in Wien 1912. Protokolle und Referate erschienen im Verlag für Fachliteratur, Wien.

zu wählen, wodurch das spezifische Gewicht für die Kennzeichnung von Benzin wohl seine sachliche Berechtigung einbüsste, aber dennoch

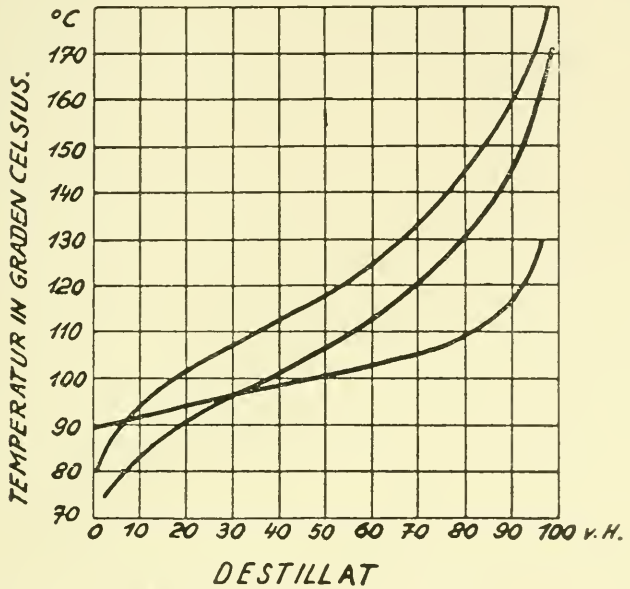


Abb. 1. Siedelinien von Benzinen.

seine alte Handelsüblichkeit beibehielt. Doch auch diese weiteren Grenzen gingen in der Entwicklung verloren, indem für die verschiedensten Sorten die verschiedensten Namen und Einteilungen gewählt wurden.[2] Die üblichsten Bezeichnungen sind jedoch: *Leicht-, Mittel- und Schwerbenzin.* Das spezifische Gewicht jeder Sorte ist annähernd durch Grenzzahlen gekennzeichnet, die sich mit steigendem Benzinbedarf stets nach oben verschieben. Dieterich[3] teilte im Jahre 1916 nach spezifischem Gewichte ein: Leichtbenzin 0,650/700, Mittelbenzin 0,701/720, Schwerbenzin 0,731/750, während vom 1. Mai d.J. handelsüblich geliefert wird: Leichtbenzin 0,725/735, Mittelbenzin 0,750/753, Schwerbenzin 0,760/765.

Der unerfahrene Verbraucher meint, stets denselben Betriebsstoff zu verwenden, wenn er nach der handelsüblichen Bezeichnung

[2]Engler-Höfer: Das Erdöl, Band IV. Seite 31, Verlag S. Hirzel, Leipzig, 1916. Donath-Gröger: Treibmittel der Kraftfahrzeuge, Seite 31, Verlag Julius Springer, Berlin, 1927.
Holde: Kohlenwasserstofföle und Fette, Seite 5, Verlag Julius Springer, Berlin, 6. Aufl. 1924.

[3]Dieterich: Unterschied und Prüfung der leichten Motorbetriebstoffe, Verlag des Europäischen Motorwagenvereines, Berlin, 1916.

Benzin vom selben spezifischen Gewicht bezieht. Ergeben sich nun nach dem Neubezug von Benzin Schwierigkeiten im Betrieb, so vermutet er vorerst Mängel im Motor, deren Aufsuchung mitunter zeitraubend ist und erst, wenn alle Bemühungen erfolglos waren, kommt er darauf, dass ihm wohl ein Benzin desselben spezifischen Gewichtes, aber mit ganz anderen Betriebseigenschaften, geliefert worden war.

Welche wechselnde Zusammensetzung Benzin desselben spezifischen Gewichtes haben kann, zeigen z.B. die im chemisch-physikalischen Laboratorium der Versuchsanstalt für Kraftfahrzeuge, Wien, ermittelten Siedelinien. (Abb. 1.)

Können also Benzinsorten desselben Ursprungsstoffes und desselben spezifischen Gewichtes in betriebstechnischer Hinsicht schon wesentliche Unterschiede aufweisen, so gilt dies weit mehr, sobald man die spezifischen Gewichte von Benzin verschiedener Ursprungsorte vergleicht. So hat z.B. Automobilbenzin von 60 bis 100° Siedepunkt ein spezifisches Gewicht von 0,680/85 aus amerikanischem, dagegen 0,695/700 aus indischem, russischem und galizischem und 0,745/50 aus Borneoerdöl.[4]

Trotzdem also das spezifische Gewicht die Eigenschaften des Benzins als Betriebsstoff nicht kennzeichnet, haben es die "Richtlinien," wenn auch nicht an erster Stelle, dennoch herangezogen, weil hierdurch bei grossen Unterschieden bis zu einem gewissen Grade das Ursprungsland erkennbar ist. Viel wichtiger aber als dieser Gesichtspunkt war, dass motortechnisch das spezifische Gewicht bei der Schwimmereinstellung des Vergasers eine Rolle spielt. Wird z.B. der Schwimmer für ein Schwerbenzin so eingestellt, dass der Brennstoff bis zur Düsenmündung reicht, so rinnt bei derselben Schwimmerbelastung Leichtbenzin über, wodurch nicht nur Brennstoff vergeudet, sondern auch Feuersgefahr heraufbeschworen wird. Diese betriebstechnischen Gründe waren vornehmlich massgebend, dass für die Kennzeichnung von Benzin an letzter Stelle auch das spezifische Gewicht herangezogen wurde.

Siedeendpunkt für 95 ccm Destillat.—Im Zündermotorenbetrieb sind die schweren Kohlenwasserstoffverbindungen unangenehm. Ihre *Verbrennung* hinterlässt auf dem Kolbenboden, auf den Ventilen und im Verbrennungsraum des Motors *Rückstände,* die den Wärmeabfluss stören und nach einer mehr oder minder langen Betriebszeit entfernt werden müssen; Zündungsklopfen,

[4]Engler-Höfer: Das Erdöl, IV. Bd. S. 501.

undichte Ventile und Mehrverbrauch an Brennstoff sind die Begleiterscheinungen verkrusteter Verbrennungsräume. Betriebstechnisch war deshalb grosser Wert darauf zu legen, dass schon bei der einfachsten Kennzeichnung von Benzin der Siedeendpunkt angegeben wird. Erfahrene Versuchschemiker stellten jedoch fest, dass die Ermittlung des Siedeendpunktes, d.h. jener Temperatur, bei der *alles* Benzin überdestilliert, besonders bei den hohen Temperaturen nicht mit genügender Genauigkeit durchgeführt werden kann. Da nun gerade diesem Punkte, dem motortechnisch die grösste Bedeutung beigelegt wird, nur geringe Messtoleranzen zugestanden werden sollten, entschloss man sich, als "Siedeendpunkt" den Siedepunkt für 95 ccm Destillat zu wählen, d.h., jene Temperatur, bei der 95 ccm von 100 ccm überdestilliert sind. Bei den heute für den Motorbetrieb üblichen Benzinsorten ist dieser Siedepunkt mit genügender Genauigkeit festzustellen; ist jedoch 95 ccm Destillat nicht erreichbar, weil schon früher Crackerscheinungen auftreten, so ist die Zahl der Kubikzentimeter anzugeben, bei der der Siedepunkt noch genau zu ermitteln ist.

Bis 100° übergehende Anteile.—Der Siedebeginn ist insbesondere bei den leichten Kohlenwasserstoffverbindungen nicht mit grosser Genauigkeit festzustellen. Nun spielen für den Motorbetrieb die bis 100° übergehenden Anteile keine so verschiedenartige Rolle, dass auf ihre Trennung nach verschiedenen Temperaturgraden besonderer Wert zu legen wäre. Deswegen, und um eine grössere messtechnische Genauigkeit zu erzielen, einigte man sich darauf, die bis 100° übergehenden Anteile zusammenzufassen, zumal sie ja alle für das Anlassen, besonders bei Tieftemperaturen, gleich gute Dienste leisten und im Betrieb selbst keine Unterschiede zeigen.

Siedeverlauf (Siedelinie).—Die Kennzeichnung von Benzin nach dem Siedeverlauf ist in Fachkreisen allgemein bekannt; es soll hier nur darauf hingewiesen werden, dass der Siedeverlauf in den normalisierten *Destillationsapparaten nach Engler-Ubbelohde* zu ermitteln und hiebei das vorgeschriebene Verfahren zu beachten ist.[5]

Arten der Kennzeichnung.—Um den verschiedenen Ansprüchen des Handels entgegenzukommen, wurden *drei Arten der Kennzeichnung von Motorenbenzin* beschlossen:

(1) "Siedeendpunkt" (für 95 ccm Destillat) und spezifisches Gewicht.

[5]Holde: Kohlenwasserstofföle und Fette. 6. Aufl. 1926, Verlag Springer, Berlin, S.101.

(2) Bis 100° übergehende Anteile in Kubikzentimetern, Siedeendpunkt (für 95 ccm Destillat) und spezifisches Gewicht.
(3) Siedeverlauf (Siedelinie) und spezifisches Gewicht.

Zur *Abkürzung* kommen folgende Zeichen in Betracht:
Für die erste Art Temperatur des Siedeendpunktes und spezifisches Gewicht, z.B. 160-750/53;
für die zweite Art die bis 100° übergehenden Anteile v.H., Siedeendpunkt und spezifisches Gewicht, z.B. 20-160-750/53;
für die dritte Art die durch eine Wellenlinie angedeutete Siedelinie und spezifisches Gewicht, z.B.~750/53.

Messtoleranzen.—Die vereinbarten Messtoleranzen sind das Ergebnis von Untersuchungen, die von verschiedenen fachkundigen Personen mit normalisierten Apparaten an mehreren Stellen durchgeführt wurden. Es zeigte sich, dass die Ermittlung der bis 100° *übergehenden Anteile* Abweichungen bis ± 5 ccm ergab, was auf die Flüchtigkeit des Leichtbenzins zurückzuführen ist. Beim *Siedeendpunkt für* 95 *ccm* liegen bei sorgfältiger Destillation kleinere Messfehler vor, weshalb die *Messtoleranz mit* ± 1 ccm festgelegt wurde.

Dass bei der Siedelinie verschiedene Toleranzen zugelassen werden, z.B. bei 94 ccm noch ± 5 ccm, bei 95 ccm. jedoch nur ± 1 ccm, ist in der Wirklichkeit nicht von Belang. Sprünge kommen in Siedelinien nicht vor, der Verlauf kann als stetig angesehen werden; daraus ergibt sich, dass die Toleranzen gegen den Siedeendpunkt stets kleiner werden und sich bei 95 ccm. dem Grenzwert ± 1 ccm nähern. Daher konnte man insbesondere im Hinblick auf die anzustrebende Vereinfachung auf die Festlegung einer eigenen Toleranzlinie verzichten.

Für das *spezifische Gewicht* wurde der Messfehler nach oben oder unten mit *einem Punkt in der dritten Dezimale* festgelegt; auch ist, wie aus den Richtlinien zu ersehen ist, für Streitfälle ein eigenes Ermittlungsverfahren zur genauen Bestimmung vorgesehen.

Gewandte Messtechniker werden finden, dass sie solch weiter Toleranz nicht bedürfen, die Grenzen hätten enger gezogen werden können. Nun ist zu bedenken, dass im Wirtschaftsleben an Personen, Messbehelfe und mitunter auch an die Zeit keine grossen Ansprüche gestellt werden können; überdies steckt in den Messtoleranzen auch etwas Warentoleranz, ein kleines Zugeständnis, das gerne gemacht wurde, weil es sich doch um eine *erste* Vereinbarung handelt, der eigentlich mehr kaufmännischer als technischer Wert zukommt.

Warentoleranzen.—Da die Messtoleranzen nicht engherzig gefasst wurden, sind Warentoleranzen nur für Sonderfälle

vorgesehen worden. Für *Markenbenzin*, wie es z.B. in den Pumpverkaufsstellen erhältlich ist, wurde die Kennzeichnung nach der *zweiten Art* bestimmt, jedoch noch Warentoleranzen in der Höhe der Messtoleranzen vereinbart; überdies sind bei dem Siedeendpunkt für 95 ccm Abweichungen von — 4 oder + 1 ccm. zugestanden.

Ferner wurde eine Warentoleranz in der Höhe der Messtoleranz zugestanden, wenn *ein* bestimmtes spezifisches Gewicht zugesichert ist.

Der Ausschuss für flüssige Brennstoffe der Gesellschaft für Wärmewirtschaft war in den zahlreichen Sitzungen stets bemüht, die verschiedenen Wünsche der Erzeuger und Verbraucher auf eine mittlere Linie zu bringen, um überhaupt zum ersten Male Richtlinien aufzustellen, die einige Klarheit in den Motorbenzinhandel zu bringen berufen sind. Es war immer peinlich, in Streitfällen, z.B. vor Gericht, hervorragende Fachleute abweichende gutächtliche Aeusserungen abgeben zu hören, weil allgemein gültige Grundlagen für die Kennzeichnung von Benzin fehlten. Sobald die nun folgenden Richtlinien sich im wirklichen Leben eingeführt haben, soll eine etwas straffere Fassung, ergänzt und berichtigt durch die inzwischen gemachten Erfahrungen, gewählt werden.

RICHTLINIEN FÜR DIE KENNZEICHNUNG VON MOTORBENZIN

(1) *Einfachste Form:*
   (*a*) Siedeendpunkt für 95 ccm. Destillat (d.i. die Temperatur, bei der 95 ccm von 100 ccm überdestilliert sind).
   (*b*) Spezifisches Gewicht.

(2) *Schärfere Kennzeichnung:*
   (*a*) Bis 100°C übergehende Anteile in Kubikzentimetern.
   (*b*) Siedeendpunkt für 95 ccm Destillat.
   (*c*) Spezifisches Gewicht.

(3) *Schärfste Kennzeichnung:*
   (*a*) Siedeverlauf (Siedelinie).
   (*b*) Spezifisches Gewicht.

I.—MESSTOLERANZEN

(A) *Bis* 100°*C übergehende Anteile*: zulässige Abweichung ± 5 ccm.

(B) *Siedeendpunkt für* 95 *ccm von* 100 *ccm:* zulässige Abweichung ± 1 ccm (94 bis 96 ccm).

(C) *Siedelinien:*[6] Bei den von 10 zu 10° zu ermittelnden

[6]Für die Schaubilder von Siedelinien sind als Abszissen die Kubikzentimeter (Raumteile v.H. der 100 ccm betragenden Füllung), als Ordinaten die Temperaturen aufzutragen. Im Streitfall ist die Nullinie aus dem arithmetischen Mittel der von zwei österreichischen, für dieses Gebiet behördlich autorisierten Versuchsanstalten gefundenen Werte zu nehmen, die jedoch untereinander höchstens 3 v.H. abweichen dürfen.

Destillatmengen sind Abweichungen bis ± 5 ccm statthaft (für den Siedeendpunkt für 95 ccm von 100 bleibt aber dennoch die zulässige Abweichung nur ± 1 ccm).

(D) *Spezifisches Gewicht:*[7] Die Angaben über spezifisches Gewicht dürfen nur um einen Punkt in der dritten Dezimale abweichen.

II.—Warentoleranzen

Für die unter besonderen Namen marktgängigen Benzine, die sogenannten *Markenbenzine:* Kennzeichnung nach 2, wobei neben der Messtoleranz noch eine Warentoleranz zugelassen ist:

(A) Bis 100° übergehende Anteile ± 5 ccm (somit Gesamttoleranz ± 10 ccm).

(B) Siedeendpunkt für 95 ccm von 100 ccm — 4 + 1 (somit Gesamttoleranz — 5 ccm + 2 ccm).

(C) Spezifisches Gewicht ± 0,004 (somit Gesamttoleranz ± 0,005).

Für *sonstiges Motorbenzin:*

(A) Bis 100° übergehende Anteile: keine Warentoleranz.

(B) Siedeendpunkt für 95 ccm von 100 ccm: keine Warentoleranz.

(C) Siedelinien: keine Warentoleranz.

(D) Spezifisches Gewicht:

(*a*) keine Warentoleranz.

(*b*) wird nur ein Wert angegeben, so gilt neben der Messtoleranz noch eine gleich grosse Warentoleranz von einem Punkt in der dritten Dezimale, so dass die Gesamttoleranz (Mess- und Warentoleranz) ± 2 Einheiten der dritten Stelle beträgt. Zum Beispiel 740 darf 738 oder 742 haben.

RÉSUMÉ

(Specially Prepared)

Classification of motor spirit by specific gravity, commonly employed in Austria by the Trade and by the Customs, was of sufficient accuracy when spirit was drawn from one source only, namely, Galicia. But since the loss of Galician supplies, and due to the many sources of origin, a specification on specific gravity alone has been found to give little indication of quality and the peculiarities which manifest themselves during consumption.

It has been clearly shown that motor spirit of the same specific gravity may have many different characteristics when examined by means of fractional distillation curves.

Consumers, having been accustomed to the single quality of spirit, are under the impression that when purchasing spirit of the same specific gravity these

[7]Bei Streitfällen zur genauen Bestimmung des spezifischen Gewichtes soll nur das Pyknometer oder eine analytische Wage zugelassen werden. Die Abweichungen sind auf einen Nullpunkt zu beziehen, der als arithmetisches Mittel von den Messungsergebnissen zweier österreichischer, für dieses Gebiet behördlich autorisierter Versuchsanstalten zu errechnen ist, die voneinander nicht mehr als 5 Einheiten in der 4. Dezimalstelle abweichen dürfen.

supplies should be of a uniform character in operation. When difficulties are experienced these are put down to the engine, whereas the spirit is the true cause on account of its varying composition.

Numerous experiments by the "Society for Fuel Economy," in conjunction with producers, factors, and consumers of motor spirit, have led to the following conclusions and suggestions.

Although the fractional distillation curves give a truer indication of the characteristics, it is necessary at the same time to quote the specific gravity, as variation from heavy to light grades give rise to trouble with the setting of the carburettor float.

The temperature at which 95 of 100 ccm. motor spirit distil over will be considered as the "Final Boiling Point." Should there be signs of cracking before the required 95 ccm. distillate can be obtained, the quantity of runnings at which the boiling point can be fixed with reasonable accuracy must be specified (in cubic centimetres).

As all fractions with a boiling point of 100°C. or less show no appreciable difference in character, they will be quoted collectively.

To comply with the various requirements of the trade, three methods of characterisation have been decided on, details of which will be found tabulated in the specification below.

These figures are subject to fixed tolerances, the result of experiments by several independent technical experts. The application of these margins and customary trade allowances is explained in the specification.

It has been the aim of the "Society for Fuel Economy" to satisfy all interested parties by striking a happy mean. As these suggestions are largely experimental and represent an initial attempt in establishing a sound basis for the characterisation of motor spirit, the proposals will be reconsidered, amended, and corrected, after they have stood the test of application in practice and when more data is available.

SPECIFICATIONS

	A.	B.	C.	D.
Simple form.		Final boiling point for 95 cm. distillate, *i.e.*, the temperature at which 95 of 100 ccm. distil over.		Specific gravity.
Stricter specification.	The quantity (in ccm.) of fractions boiling at 100°C. or less.	Final boiling point for 95 ccm. distillate.		Specific gravity.
Strictest specification.			Fractional distillation curve.	Specific gravity.

TOLERANCES

	A.	B.	C.	D.
Tolerances on measurement.	Fractions boiling at 100°C. or less: ± 5 ccm.	Final boiling point for 95 ccm. distillate ± 1 ccm.	Fractional distillation curves: Fractions boiling between successive 10°C. ranges ± 5 ccm. (but for the final boiling point for 95 ccm. only ± 1 ccm. as in B).	Specific gravity ± ·001
Trade tolerances on branded motor spirits.	Fractions boiling at 100°C. or less: ± 5 cm. (making a total tolerance of ± 10 ccm.).	Final boiling point for 95 ccm. distillate: — 4 ccm. + 1 ccm. (total tolerance: — 5 ccm. + 2 ccm.).		Specific gravity: ± ·004 (total tolerance ± ·005).
Trade tolerances on other motor spirits.	Fractions boiling at 100°C. or less. No trade tolerance.	Final boiling point for 95 ccm. distillate. No trade tolerance.	Fractional distillation curves. No trade tolerance.	Specific gravity (*a*) No trade tolerance. (*b*) If a definite figure only is quoted an additional allowance of ± ·001 is granted (total tolerance ± ·002).

THE AVAILABILITY OF THE ALBERTA BITUMINOUS SANDS FOR PRODUCTION OF FUEL OIL

SCIENTIFIC AND INDUSTRIAL RESEARCH COUNCIL OF ALBERTA

K. A. CLARK

Paper No. F2

CONTENTS

OCCURRENCE—RECOVERY OF OIL—MANUFACTURE OF FUEL OILS—BIBLIOGRAPHY—RÉSUMÉ

The purpose of this paper is to give, very briefly, a statement of the information now available regarding the bituminous sands of Alberta and their potentialities as a source of liquid fuel. Increasingly frequent reference is being made to this occurrence in discussions of the sources of liquid fuel throughout the British Empire and the world.[1]

Occurrence.

The bituminous sand formation lies along the Athabaska river in the northern, unsettled part of the Province of Alberta, the southern edge of the area being 300 miles north of the city of Edmonton. Transportation is provided by shallow draft navigation on the Athabaska river through the bituminous sand area, and by railway from the head of navigation to Edmonton.

The formation varies from 100 to 200 ft. in thickness, and is revealed by numerous exposures along the Athabaska and tributary rivers throughout an area of from 750 to 1,000 square miles. The formation as a whole is covered with an overburden of unconsolidated material varying in thickness from less than 50 ft. to over 100 ft.

Well impregnated beds have a bitumen content of from 10 to 16 per cent. by weight, the bitumen being a soft asphalt which will pour very sluggishly at ordinary temperatures. It has a specific

gravity at 25°C. of from 1.000 to 1.025, and a sulphur content of from 4 to 5 per cent. The mineral constituent is sand, silt and clay, the sand particles consisting mainly of quartz and varying in size from 50 to 200 mesh. Coarser sand does occur, but the finer particles generally predominate. Material passing the 200 mesh sieve is almost invariably present to the extent of several per cent., and may be as high as thirty per cent. of the mineral constituent in well impregnated sand.

The bituminous sand formation consists of lenticular beds of sand, silty sand and clay. The degree of impregnation of these beds with bitumen is closely associated with the silt and clay content. The sand is rich in bitumen, silty beds tend to be lean, while the clay beds have practically no bitumen content. Owing to the lenticular structure of the formation, vertical and lateral variations are pronounced, there being a decided tendency for the lower beds of the formation to be the less silty ones and consequently rich in bitumen.

The most favourable locations for initial commercial development are in the valleys of the Athabaska and tributary rivers. Places are to be found where erosion has removed not only the loose covering of the formation but also the upper lean bituminous sand beds. Large tonnages of consistently rich material lightly covered with loose drift are available for substantial first steps in development work, and once industry is established, accumulating experience and changing economic conditions will lead on to the utilisation of the main mass of the bituminous sand formation.

The Mines Branch of the Department of Mines, Ottawa, has surveyed the bituminous sand area topographically and has published maps, together with a report containing much general information.[2] The Scientific and Industrial Research Council of Alberta has made detailed cross-sections of some thirty-five exposures distributed throughout the area, and descriptions of these cross-sections, along with the analyses of the complete suites of samples have been published.[3]

Recovery of Oil

Many processes have been tried or proposed for recovering oil from bituminous sand, an excellent summary of these being given in the report No. 632 of the Mines Branch already referred to.[2] The general process of separation by means of hot water has been

studied by the Scientific and Industrial Research Council of Alberta, and adapted to the Alberta bituminous sands.[4]

The procedure used consists of a preliminary heating and mixing of the bituminous sand with about one-fifth of its weight of dilute silicate of soda solution and of a subsequent washing of the treated material into a comparatively large body of hot water. The bitumen floats to the surface of the water, the latter being used over and over again. The procedure has been carried out on semi-commercial scale with satisfactory results, and analysis of available data indicates a cost of about one dollar per barrel of recovered bitumen for mining the bituminous sand and separating it.

Manufacture of Fuel Oils

The most efficient method of preparing fuel oils from the bituminous sand would appear to be that of submitting the separated bitumen to the cracking processes that are being rapidly developed and used by the petroleum industry. Cracking tests have been made with two commercial cracking processes on separated bitumen produced by the Scientific and Industrial Research Council. One was made by the Universal Oil Products Co., using the Dubbs Cracking Process,[4] and the other by the Kansas City Testing Laboratory, using the Cross Cracking Process.[5] In the case of the Dubbs test, the bitumen was cracked directly, while in the case of the Cross test, the bitumen was first distilled in a fire still and the distillate cracked. Both testing laboratories reported a gasoline yield of over 35 per cent., along with from 15 to 20 per cent. of fuel oil, and also commented on the exceptionally good anti-detonating property of the cracked gasoline.

A crude oil distillate can be produced directly from the bituminous sand by retorting.[2] A sample of separated bitumen was sent to Germany for berginisation test, but no official results are available. Professor Nash has published some data on hydrogenation experiments in his laboratory.[1]

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RÉSUMÉ

Ce rapport contient un bref exposé des principaux faits concernant la présence et la possibilité de se procurer des sables bitumineux dans la province d'Alberta, Canada. Les progrès qui ont été realisés par la méthode dite "d'eau chaude" et qui consiste à séparer le bitume du sable y sont indiqués. Les résultats des essais pour la production de combustibles liquides par la méthode de craquage, en usage dans le commerce, y sont également donnés. On y trouvera enfin des références aux rapports adressés au gouvernement sur les sables bitumineux de l'Alberta.

ANFORDERUNGEN DES KRAFTFAHR- UND FLUGZEUGWESENS AN DIE FLUSSIGEN BRENNSTOFFE, UND BEFRIEDIGUNG DER VORERWÄHNTEN ANFORDERUNGEN DURCH DIE HEUTIGE ÖLINDUSTRIE

(PROPERTIES REQUIRED OF LIQUID FUELS FOR USE IN AUTOMOBILE AND AIRCRAFT ENGINES, AND HOW THE OIL INDUSTRY MEETS THESE REQUIREMENTS)

AUTOMOBIL- UND FLUGTECHNISCHE GESELLSCHAFT, BERLIN, UND BENZOL-VERBAND, BOCHUM

WA. OSTWALD

Paper No. F3

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GENERAL—GENERAL PROPERTIES OF LIQUID FUELS—PRODUCTION AND SUPPLY OF FUELS—GENERAL CHARACTERISTICS—UNIMPORTANT CHARACTERISTICS—IMPORTANT CHARACTERISTICS—HOW THE OIL INDUSTRY MEETS REQUIREMENTS—PROPOSED SPECIFICATIONS
ENGLISH VERSION (ABRIDGED)

ALLGEMEINES.—Zweck der Kraftfahrzeuge (Kraftwagen, Motorboote, Flugzeuge und Luftschiffe) ist rascher (zwischen etwa 20 km/Stunde und 200 km/Stunde) Ortswechsel von Personen oder anderen Nutzlasten. Zu diesem Zwecke muss die Gesamtmasse von Nutzlast und Fahrzeuggewicht mit der kinetischen Energie behaftet werden, welche Weg und Zeit, mithin der Reisegeschwindigkeit entspricht. Hinzu kommt zusätzlicher Energieaufwand zur Ueberwindung der Widerstände von Luft, Boden, Wasser, von Wegnotwendigkeiten (Steigungen, Geschwindigkeitsveränderungen aus äusseren Gründen u.a.). Der Energieaufwand geht bis zum Anhalten des Fahrzeugs restlos als Wärme verloren.

Zur Wahrung seiner räumlichen Freiheit führt das Kraftfahrzeug seinen hiernach erforderlichen Energiebedarf in stofflich gebundener

Form mit sich. Die Uebertragung von Energie ohne zugeordnete Materie auf das freie Fahrzeug (z.B. drahtlose elektrische Kraftübertragung) ist für praktische Zwecke noch nicht gelöst. Die "Aufladung" von Kraftfahrzeugen mit materiefreier Energie durch Umwandlung von ein für alle Male auf dem Kraftfahrzeug befindlicher Materie hat in Gestalt elektrischer Akkumulatoren nur sehr beschränkte Anwendungsbereiche gefunden. Eine scheinbar gewichtslose Energiequelle ist bei den Flugschiffen "leichter als Luft" durch Verwendung von Blaugas (Oelgas besonderer Art vom spez. Gewicht 1,05-1,10 bei Luft gleich 1,00, mit 15 500 WE/cbm) durch die Zeppelin-Werke in Friedrichshafen eingeführt worden.

Als best geeignete Energieform, welche zeitlich beständig ist und die willkürlich regelbare Umwandlung in die benötigte mechanische Energie vorteilhaft gestattet, hat sich die chemische Energie von Kohlenwassertoffen, Alkoholen und verwandten organischen Verbindungen herausgestellt. Die Umwandlung der chemischen Energie in mechanische erfolgt in Verbrennungsmotoren auf dem Umwege über Gasdruck bei hoher Temperatur, der durch periodische Verbrennung des Kraftstoffs in verdichteter Luft bezw. Sauerstoff erzeugt wird.

Der Energiegehalt eines Kraftstoffes ist deshalb durch seinen Heizwert bestimmt. Dieser hängt ab

(1) vom Kohlenstoffgehalt,
(2) vom Wasserstoffgehalt,
(3) vom Sauerstoffgehalt, der als "anteilige Verbrennung" wirkt und den Heizwert verkleinert,
(4) von der Besonderheit der chemischen Bindung (die bei aliphatischen Kohlenwasserstoffen den Energiegehalt verkleinert und ihn z.B. beim Benzol etwas, beim Azetylen stark erhöht),
(5) von etwaigen Verunreinigungen (Schwefel zeigt Heizwert je nach seiner Bindungsform, Asche verkleinert den Heizwert proportional ihrem Prozentsatz).

Man kann den Heizwert üblicherweise auf das Einheitsgewicht des Kraftstoffs (kg) beziehen. Offenbar ist ceteris paribus ein Kraftstoff ganz allgemein umso günstiger, je kleiner sein "Energiegewicht" (Kraftstoffgewicht je 1 000 kcal) ist :

ENERGIEGEWICHTE

Kraftstoff:	Gramm je 1 000 kcal.
Benzin...	95
Benzol...	104
Spiritus	165
Methanol	214

Das Energiegewicht spielt eine grosse Rolle bei Kraftfahrzeugen hoher Fahrgeschwindigkeit mit häufiger Beschleunigung, bezw. stark wechselnder Fahrgeschwindigkeit (Personenkraftwagen), sowie solchen, welche die Erdschwere überwinden müssen (Flugzeuge, Luftschiffe), und eine geringere bei solchen mit geringer Fahrgeschwindigkeit (Lastkraftwagen) und verhältnismässig seltenem Geschwindigkeitswechsel (Motorboote).

Man kann den Heizwert auch auf das Kraftstoffvolum beziehen (kcal/Liter).

ENERGIEVOLUMINA

Kraftstoff:	cc je 1 000 kcal.
Benzin...	127
Benzol...	119
Spiritus	204
Methanol	271

Das Energievolum eines Kraftstoffes hat grosse praktische Bedeutung für alle Kraftfahrzeuge, weil Kraftstoffe international überwiegend nach Volum verkauft werden und bei gegebenem Tankinhalt das Energievolum den Aktionsradius des Kraftfahrzeuges bestimmt.

Endlich muss man den Heizwert oder Energiegehalt eines Kraftstoffes auch auf den Marktpreis beziehen und gelangt so zu dem "Energiepreis" eines Kraftstoffs (Pfennige je 1 000 kcal). Der Energiepreis schwankt naturgemäss stark mit den Marktverhältnissen und beträgt z.B. (März 1928) in Deutschland für Benzin und Benzol 3-4 Pfennige je 1 000 kcal. Bei gleichem spezifischem Wärmeverbrauch und gleicher technischer Brauchbarkeit ist der Energiepreis die massgebende Grundlage zur Beurteilung eines Kraftstoffs. Dies ist wichtig, weil zwar die leichtsiedenden, flüssigen Kraftstoffe (Siedekennziffer bis etwa 140 Grad C) nur wenig verschiedene Energiepreise haben, jedoch der Energiepreis der höher siedenden, flüssigen Kraftstoffe (Gasöle, Dieselöle, KZ ca. 275 Grad C) sehr erheblich niedriger ist. (Dass z.B. die zwischenliegenden, flüssigen Kraftstoffe vom Typ des Leuchtpetroleums (KZ ca. 200 Grad C) z.Zt. die höchsten Energiepreise haben, wird man als vorübergehende, zufällige Erscheinung ansehen dürfen.)[1] Der Umstand, dass die "Qualitätskalorie" des Benzins z.B. etwa doppelt so viel kostet, wie die chemisch sehr ähnliche Gasölkalorie, ist ein starker Anreiz sowohl für Chemiker, Gasöl in Benzin zu verwandeln, wie für die Motorenbauer, den Fahrzeugdieselmotor zu entwickeln.

[1] Derartige Zufälligkeiten werden insbesondere durch die Eigenart der Zölle begünstigt.

Ausser dem Kraftstoff selbst ist auch sein energetischer Gegenpol, der Sauerstoff der Verbrennungsluft, als Energieträger zu betrachten, In seiner normalen Konzentration, wie er in der atmosphärischen Luft bei normalem Barometerstand vorliegt, bedarf er keiner besonderen Betrachtung, weil er gleichsam die Nullinie für die Energiegewinnung darstellt. Schon die Aenderung der absoluten Konzentration, wie sie etwa der Wechsel des Barometerstandes, der Automotorbetrieb in grösseren Höhen, der Kompressor- und der Drosselbetrieb darstellen, ändern zwar nicht den Heizwert des Kraftstoffs, wohl aber den Wirkungsgrad seiner Ausnützung. In noch viel stärkerem Grade gilt dies für die gelegentlich versuchte (aber praktisch noch nicht bedeutungsvoll gewordene) Verwendung Sauerstoff-angereicherter Luft bezw. reinen Sauerstoffs für die motorische Verbrennung. Die Verbrennung reinen Sauerstoffs würde bei technischer Beherrschung der auftretenden hohen Temperaturen und sonstigen technischen Schwierigkeiten nicht nur eine Verfünffachung der Literleistung, sondern zugleich eine sehr erhebliche Verbesserung des Wirkungsgrades der Energieumwandlung selbst mit sich bringen.

Die Frage der "Qualitätskalorie."—Der Kraftverkehr verlangt einerseits einen möglichst billigen Kraftstoff, der den Nutztonnenkilometer möglichst niedrig einstehen lässt. Bei entsprechend niedrigem Energiepreis sind hier Opfer an thermischem Wirkungsgrad möglich.

Andererseits verlangt der Kraftverkehr möglichst bequeme Kraftstoffe, welche betriebssicher in leichten Motoren mit mangelhafter Wartung verwendet werden können. Für grosse "foolproofness" eines Kraftstoffs können Opfer sowohl an Wirkungsgrad, wie an Energiepreis gebracht werden.

Die praktischen Aufgaben des Kraftverkehrs liegen zwischen diesen beiden Extremen, deren eines durch den "Luxuskraftstoff" für den Herrenfahrer, deren anderes durch den "Nutzkraftstoff" für den Lastkraftwagen- und Fischerbootbetrieb angedeutet wird.

Es handelt sich um den Betrag von technischem Aufwand zur Aufbereitung der verbrennlichen Ladung, der auf dem Kraftfahrzeug selbst aufgewendet werden soll und darf. Im Extremfall des Herrenfahrers ist dieser technische Aufwand auf ein Minimum zu beschränken. Der Kraftstoff muss foolproof sein, obwohl an ihn, bezw. den Motor bezüglich sofortiger Betriebsbereitschaft, Betriebssicherheit, sauberer Verbrennung, Fähigkeit, plötzliche Belastungswechsel zu ertragen, Geruchlosigkeit von Kraftstoff und

Verbrennungsprodukten usf. die allergrössten Anforderungen gestellt werden. Bei solchen "Luxuskraftstoffen" muss ein möglichst grosser Teil des technischen Aufwandes bereits durch Auswahl und Bearbeitung des Kraftstoffs geleistet sein, bevor er in den Fahrzeugtank fliesst.

Umgekehrt darf auf einem Nutzfahrzeug, bei dem es in erster Linie auf die Billigkeit des Nutztonnenkilometers ankommt, das Mass der Ansprüche an sorgfältige Bedienung, an Umstände beim Anlassen, Raumbedarf besonderer Einrichtungen usw. ziemlich hoch geschraubt werden, wenn dadurch die Verwendung sehr billiger Kalorien ermöglicht wird. Man wäre z.B. sogar bereit, den sehr erheblichen Platz- und Gewichtsbedarf der Sauggaserzeuger zusammen mit ihrer lästigen Bedienung in Kauf zu nehmen, wenn sich dabei eine günstige Wirtschaftlichkeit ergäbe. Da die Kraftstoffkosten nur 20–30% der Betriebskosten eines Kraftfahrzeugs ausmachen, so sind die möglichen Ersparnisse nicht sehr gross, während etwaige erhöhte Bedienungskosten, Reparaturen usw. sich sehr stark auswirken.

Aus diesem Wettstreit von Motorenbau und Kraftstoffchemie haben sich zwei Kraftstofftypen international herausgebildet, der Auto-Kraftstoff und das Dieselöl, die sich im wesentlichen durch ihr Siedeverhalten (KZ 110–140 bezw. 225–300) unterscheiden. Diesen beiden Kraftstofftypen entsprechen als Motorengattungen der Vergasermotor mit Fremdzündung und der Diesel- und Glühkopfmotor mit Selbst- bezw. Glühzündung. Zwischentypen von Motoren befinden sich in der Entwicklung. Der Zwischentyp des Kraftstoffs, das Leuchtpetroleum, ist z.Zt. unwirtschaftlich teuer.

Entsprechend ihren Arbeitsverfahren beeinflussen die beiden Motorenarten die Entwicklung der Kraftstoffe. Der Vergasermotor drängt zwecks Steigerung seiner Literleistung, Kiloleistung, Wirtschaftlichkeit zu hohen Verdichtungsverhältnissen, welche möglichst kompressionsfeste Kraftstoffe von aromatischem bezw. naphtenischem oder von alkoholischem Charakter erwünscht machen. Gleichzeitig fördert er die Entwicklung von Klopfbremsen, wie Eisenkarbonyl (Motalin) und Tetraäthylblei (Ethylgas). Umgekehrt strebt der Fahrzeugdieselmotor nach grösstmöglicher Verringerung der Verdichtung zwecks Erleichterung des Gewichtes und der Betriebsbequemlichkeit. Er bevorzugt deshalb ausgesprochen aliphatische Kraftstoffe und würde durch jedes Mittel zur Verbesserung der Selbstzündung (z.B. Proklopfmittel) in seiner Entwicklung gefördert werden. Gleiches gilt für den Glühkopfmotor.

Die Versuche, den Vergasermotor mit hochsiedenden Kraftstoffen

zu betreiben, haben trotz vielfältiger Bemühungen bisher zu keinem befriedigenden Ergebnis geführt. Hauptgrund dafür ist die leicht eintretende Oelverdünnung, die besonders rasch beim Versagen einer Zündkerze auftritt, weil unverbrannte Schweröllladungen unvergleichlich stärker im Verbrennungsraum kondensieren, als dies bei Leichtkraftstoffbetrieb unter gleichen Verhältnissen der Fall ist.

Ein Bedürfnis für einen Schwerölvergaserbetrieb würde bei Flugzeug- und Luftschiffmotoren solange bestehen, als der in Entwicklung begriffene leichte Dieselmotor noch nicht vorliegt. Dieses Bedürfnis beruht auf der Tatsache, dass die grosse Feuergefährlichkeit der Leichtkraftstoffe auf Luftfahrzeugen besonders bedenklich ist. Andererseits schaffen die gute Wartung, die Möglichkeit, eine Anlasszeit in Kauf zu nehmen, und vor allem die verhältnismässig gleichförmige Belastung der Luftfahrtmotoren sehr günstige Voraussetzungen für einen Schwerölvergaserbetrieb. Es möchte deshalb dankenswert erscheinen, die Verwendung möglichst kompressionsfester, scharf fraktionierter Kohlenwasserstoffe von KZ ca. 180° C, welche ganz erheblich verringerte Feuergefährlichkeit zeigen würden, an Luftfahrtmotoren mit entsprechend veränderten Vergasereinrichtungen zu studieren.

Es hat den Anschein, dass die Frage der Qualitätskalorie ihre Schärfe verliert. Diese war früher durch die Zwangsläufigkeit gegeben, mit der bei der Erdölverarbeitung die Mengen der verschiedenen Siedebereiche anfielen. Die neuere Entwicklung der Crackverfahren hat hier schon grosse Freiheit gebracht. Die neueste Entwicklung der katalytischen Hochdrucksynthese, welche letzten Endes die 100-prozentige Umwandlung jedes Roh-Kohlenwasserstoffes in jeden gewünschten Kohlenwasserstoff-Kraftstoff gestattet, lässt die Frage der Qualitätskalorie zu einem wirtschaftlichen Rechenexempel werden. Noch liegen ausreichende Erfahrungen über die Kosten der verschiedenen Umwandlungen nicht vor. Sobald diese jedoch vorliegen, und sich wirtschaftlich ausgewirkt haben werden, wird der Motorenbauer zuverlässiger als heute errechnen können, wann sich der technische Aufwand zur Verwendung billiger Kalorien lohnt und wann nicht.

Allgemeine Eigenschaften der flüssigen Kraftstoffe.—Von der Erörterung gasförmiger (Blaugas für Luftschiffe, verdichtetes Methan aus Koksofengas für Omnibusse, Azetylen usw.) und fester (Naphtalin, Holz, Holzkohle usw. im Sauggasgenerator, Kohlenstaub usf.) Kraftstoffe wird abgesehen.

(*a*) *Korrosion.*—In den Kraftstoffsystemen der Fahrzeuge kommen Kupfer, Blei, Zink, Aluminium, Magnesium und ihre Legierungen vor. Diese werden zuweilen von Kraftstoffen angegriffen. Ursachen für die Angriffe sind u.a. Säurereste aus der Raffination, elementarer und lose gebundener Schwefel (als Thiophen, Schwefelkohlenstoff usw. greift Schwefel die Metalle nicht an), aromatisch gebundenes Hydroxyl in Gestalt von Naphtensäuren und Phenolen, unbekannte Verbindungen in mangelhaft raffiniertem Spiritus. Diese Korrosionen gehen zuweilen so weit, dass Verstopfungen von Rohrleitungen vorkommen. Die Schwefelkorrosion hat die spezifische Wirkung, Kupfer und Messing brüchig zu machen. Zinn ist fest gegen Kraftstoffkorrosion, sodass durch ausreichend dichte Verzinnung aller kraftstoffbespülten Teile am Kraftfahrzeug die Korrosionsgefahren ausgeschaltet werden können. So lange dies nicht der Fall ist, muss von allen Kraftstoffen Korrosionsfreiheit gefordert werden.

Die Prüfung kann durch einwöchentliches Stehenlassen einer Kraftstoffprobe mit den betreffenden Metallen als Blechstreifen und Beobachtung des Angriffs erfolgen.

(*b*) *Lagerbeständigkeit.*—Es ist zu fordern, dass Kraftstoffe bei normaler Lagerung, also in geschlossenen Behältern aus Eisen, verzinktem oder verbleitem Eisenblech sich in z.B. 6 Monaten nicht nachteilig verändern. Diese Gefahr besteht bei manchen leichtsiedenden Kraftstoffen insofern, als ihr Abdampfrückstand sich unzulässig erhöht. Ursache pflegt ungenügende Raffination zu sein

Prüfung ist durch den Abdampftest eines 6 Monate gelagerten Kraftstoffs möglich. 100 cc sollen beim Abdampfen auf dem Wasserbade nicht mehr als 50 mg Rückstand liefern.

(*c*) *Freiheit von Wasser und Schmutz.*—Trotzdem die Kraftstoffsysteme fast aller Kraftfahrzeuge mit Vorrichtungen zur Abscheidung von Wasser und Schmutz versehen sind, muss bei der Empfindlichkeit der Vergaser auf Beides und der Kraftstoffpumpen auf Schmutz, sowie der Unzuverlässigkeit der Seihersiebe unter Betriebsverhältnissen, weitgehende Freiheit von Wasser und Schmutz gefordert werden. Da—mit ganz seltenen Ausnahmen—Wasser und Schmutz sich selbsttätig durch ihre Schwere abscheiden, ist diese Forderung mehr an die Einrichtungen zur Kraftstoffverteilung, als an den Kraftstoff selbst zu stellen. Da Rostbildung und (wegen des mit der Temperatur schwankenden Wasserlösevermögens von Benzin und Benzol für Wasser) Wasserabscheidung praktisch unvermeidbar sind, müssen diejenigen Stellen, welche das Kraftfahrzeug betanken, mit entsprechenden Einrichtungen ausgestattet

sein (Siebe wirken nicht, wenn sie nicht mit Schwere-Abscheidern verbunden sind). Bei Spritgemischen, welche kein Wasser abscheiden, setzt sich der Schmutz in den Seihern als feste Masse ab, was bei ihrer Konstruktion berücksichtigt werden muss.

(*d*) *Geruch.*—Gewisse Kraftstoffe haben einen ausgesprochenen und manchen Personen widerwärtigen Geruch. Dieser kann sowohl eine Eigenschaft des unverbrannten Kraftstoffs sein (bei schlechter Reinigung), als auch eine Eigenschaft der Auspuffgase (zumal bei durch reiche Vergasereinstellung hervorgerufener unvollständiger Verbrennung); z.B. ruft unvollständig verbranntes Tetralin Tränen der Augen bei beizendem Geruch hervor, Auspuffgase unraffinierten Gaswerksbenzols riechen sehr schlecht, Benzine mit hochsiedenden aliphatischen Bestandteilen ("Siedeschwänzen"), manche Crack- und Braunkohlenbenzine geben zumal bei unvollständiger Verbrennung belästigende, penetrante Gerüche. Gasöl (Dieselöl) erzeugt bei der Verbrennung im Glühkopf- und im Dieselmotor Auspuffgase, die vermöge eines sehr kleinen Gehaltes von charakteristischen Produkten der unvollständigen Verbrennung sehr unangenehm riechen und die Schleimhäute reizen, ein Uebelstand, der durch Zusatz von Alkoholen, durch Wassereinspritzung, sowie durch günstigere Gestaltung der Verbrennung (Junkers Gegenkolbenmotor) zu verbessern versucht wird. Es ist angesichts der Belästigung der Führer, der Belästigung der Fahrgäste, Schädigung empfindlicher Nutzlasten (z.B. Nahrungsmittel) und Verunreinigung der Grosstadtluft eine Entwicklung der Kraftstoffe dahin anzustreben, dass sie weder als Kraftstoff, noch als Abgas belästigend stark riechen.

(*e*) *Giftigkeit.*—Alle leichtflüchtigen Kraftstoffe wirken als Dämpfe zunächst für alle atmenden Lebewesen erstickend. Darüber hinaus sind narkotische bis spezifisch giftige Wirkungen beobachtet worden, die etwa in der Reihenfolge

Benzin,
Benzol,
Alkohol,

zunehmen.

Giftig sind ferner die Abgase der Motoren durch ihren Gehalt an Kohlenoxyd. Dieser hängt einmal von der Güte der Vergasereinstellung ab, zum anderen aber auch von der Neigung des Kraftstoffs zu unvollständiger Verbrennung. Alkoholgehalt eines Kraftstoffes begünstigt vollständige, Gehalt an hochsiedenden Bestandteilen und hoher Kohlenstoffgehalt begünstigen unvollständige Verbrennung. Man versucht, durch bessere Vergasereinregelung

(z.B. mit Hilfe der Abgasanalyse) aber auch durch ev. katalytische Nachverbrennung der Abgase Giftigkeit und Geruch der Abgase zu beseitigen.

Direkt giftig durch seinen Gehalt an Tetra-Aethylblei ist das Ethylgas. Durch rote Färbung und besondere Vorsichtsmassnahmen ist man bemüht, Unglücksfällen vorzubeugen. Unvermeidlich ist jedoch die Abscheidung von Bleiverbindungen im Motor und die Verunreinigung des Strassenstaubes durch die bleihaltigen Auspuffgase. Bei der von vielen Medizinern behaupteten akkumulierenden Beschaffenheit der Bleivergiftung bestehen so starke hygienische Bedenken gegen seine allgemeine Verwendung, dass eine Einführung in Deutschland auf Schwierigkeiten stossen dürfte. Da es dem Eisenkarbonyl technisch unterlegen ist, würde in Deutschland auch kein Bedürfnis zur Einführung bestehen.

(*f*) *Hautreizung durch Kraftstoffe.*—Die Kraftstoffe wirken auf die Haut entfettend, was eine gewisse, in der Regel belanglose Hautreizung bewirkt. Darüber hinaus bestehen individuelle Empfindlichkeiten der menschlichen Haut gegen gewisse Kraftstoffe. Bei Benzin und Gasöl sind solche nicht bekannt, Steinkohlenteeröl und Tetralin scheinen entsprechend ihrem grossen Lösungsvermögen am leichtesten zu derartigen Schwierigkeiten (Entzündungen der Haut, Exzeme) Anlass zu geben.

(*g*) *Lacklösevermögen.*—Lackierungen auf Leinölgrundlage, wie sie im Kraftfahrzeugbau üblich sind, zeigen sich unempfindlich gegen Benzin und Gasöl, wenig empfindlich gegen Benzol und Steinkohlenteeröl, recht empfindlich gegen Alkoholgemische, Tetralin und dgl. Abgeschwächt gilt die gleiche Reihenfolge für die neueren Zelluloselacke. Es gibt jetzt Lacke, die gegen alle in Betracht kommenden Kraftstoffe ausreichend unempfindlich sind. So lange diese nicht allgemein eingeführt sind, wird man dem Lacklösevermögen der Kraftstoffe Aufmerksamkeit schenken müssen.

(*h*) *Mischbarkeit.*—Kohlenwasserstoffkraftstoffe (Benzin, Benzol, Gasöl Steinkohlenteeröl, Braunkohlenteerdestillate) sind in allen Verhältnissen ineinander löslich. Vollkommen wasserfreier Alkohol mischt sich ebenfalls in allen Verhältnissen mit Kohlenwasserstoffen. Da die technischen Alkohole nicht vollkommen wasserfrei sind, bezw. durch Wasseranziehung diese Eigenschaft verlieren können, erfordern alkoholhaltige Mischkraftstoffe in der Regel besondere Vorsichtsmassregeln beim Mischen mit Kohlenwasserstoffen, wenn anders nicht Neigung zu Entmischung oder Verringerung der Kältefestigkeit eintreten soll (z.B. Zusatz von hydrierten Phenolen oder

höheren Alkoholen als "Homogenisierungsmittel," Einhaltung bestimmter Mengenverhältnisse).

(*i*) *Kältefestigkeit.*—Das Mass der erforderlichen Kältefestigkeit beträgt für Kraftwagen −15 bis −25 Grad C; bei Flugzeugen wird man noch höher in den Anforderungen gehen müssen; Benzin ist vollkommen kältefest. Gasöl zeigt starke Vergrösserung der Viskosität. Steinkohlenteeröl neigt zu Abscheidungen von Naphtalin usf. Reinbenzol gefriert bei −4 Grad C. Bei Gehalt an Toluol und anderen Homologen (B.V.-Typ) erhöht sich die Kältefestigkeit (Abscheidung erster Benzoleiskristalle bei −15 Grad C), bei Zusatz von Benzin oder von Alkohol noch weiter. Alkohole sind für sich und im Gemisch mit Kohlenwasserstoffen ungemein kältefest. Schon sehr kleine Wassergehalte bewirken aber Neigung zum Zerfall in zwei flüssige Schichten bei Senkung der Temperatur. Benzin ist in Alkoholgemisch entmischungsempfindlicher als Benzol. Höhere Alkohole, hydrierte Phenole und andere "Homogenisierungsmittel" setzen die Entmischungstemperatur herab.

(*k*) *Wasserempfindlichkeit.*—Benzin löst sehr kleine Mengen Wasser, bei höherer Temperatur etwas mehr. Darum scheidet Benzin beim Abkühlen etwas Wasser ab. Bei Benzol liegen die gleichen Verhältnisse verstärkt vor. Mischt man Benzin und Benzol, wenn beide wassergesättigt sind, scheidet sich Wasser ab. Bei der Wasserabscheidung sammeln sich suspendierte feste Verunreinigungen (Rost) in der Grenzschicht zwischen den beiden Phasen, ein Umstand, der das "Ablassen" von Rostschlamm erleichtert. Bei Spritgemischen besteht je nach der Zusammensetzung ein Wasserlösevermögen im Ausmasse von bis zu mehreren Prozenten, dessen Beanspruchung jedoch rasch zur Verringerung der Kältefestigkeit, schliesslich zur Entmischung führt. Der "Wassertiter" bei gegebener Temperatur (Anzahl cc Wasser je 100 cc Kraftstoff, welche zu bleibender Trübung führen) ist ein bequemes Mittel zur Beurteilung der Hochprozentigkeit des in einem Spritgemisch enthaltenen Alkohols.

(*l*) *Erzeugungsmenge und Erhältlichkeit.*—Bei der Ortsungebundenheit der Kraftfahrzeuge kann sich ein Kraftfahrzeug—von Ausnahmen abgesehen—nicht auf erhebliche Besonderheiten eines Kraftstoffs einstellen. Umgekehrt können Kraftstoffe mit erheblichen Besonderheiten sich nur dann auswirken, wenn sie in verhältnismässig grosser Erzeugungsmenge vorliegen und leicht erhältlich sind. Z.B. spielt in Deutschland das in sehr erheblichem Prozentsatz vorliegende Benzol als Kraftstoff unvermischt und als Gemisch eine so grosse Rolle, dass es eine (vorteilhafte) Erhöhung des Verdichtungsverhältnisses der Motoren nach sich zog. In den U.S.A.

ist die absolut grosse Benzolerzeugung relativ zum Verbrauch so klein, dass die vom Motorenbauer angestrebte Verdichtungserhöhung sich nur sehr langsam entsprechend der Erhöhung der Kompressionsfestigkeit der amerikanischen Benzine fortentwickeln kann. Entsprechend pflegt man bei deutschen Motoren zum Export das Verdichtungsverhältnis zu vermindern, während international verkehrende Kraftfahrzeuge (z.B. Flugzeuge) besondere Rücksicht auf die Kompressionsfestigkeit der erhältlichen Kraftstoffe nehmen müssen.

In Deutschland stehen verhältnismässig sehr grosse Mengen an kompressionsfestem Kraftstoff zur Verfügung. Für 1927 betrug z.B. die deutsche Benzolerzeugung ca. 300 000 tons, wozu ein Einfuhrüberschuss von 114 000 tons kam. Von diesen 414 000 tons wurden verhältnismässig nur geringe Mengen von der chemischen Industrie, der Kautschukindustrie und anderen Zwecken in Anspruch genommen, sodass annähernd 400 000 tons Benzol für motorische Zwecke zur Verfügung standen. Der Gesamtverbrauch Deutschlands an Motorkraftstoffen betrug 1927 800 000–900 000 tons, sodass der Verbrauch nahezu zur Hälfte mit Benzol hätte gedeckt werden können, bezw. dass man ein 40–50 prozentiges Benzin-Benzol-Gemisch für alle Motoren hätte liefern und das Verdichtungsverhältnis der Motoren auf einen solchen Kraftstoff hätte einstellen können.

Tatsächlich ist von der gesamten Benzolmenge 1927 ein nicht unerheblicher Bruchteil unverkauft geblieben. Auch ist von dem verbrauchten Benzol eine erhebliche Menge unvermischt verbrannt worden, während andererseits unvermischtes Benzin in erheblichen Mengen Verwendung fand. Zur Beurteilung der Lage ist ferner die Tatsache heranzuziehen, dass nicht unerhebliche Mengen von Motalin (durch Eisenkarbonylzusatz in seiner Kompressionsfestigkeit gesteigertes Benzin) und Monopolin (ziemlich kompressionsfestes Spiritus-Benzin-Benzol- bezw. Alkohol-Benzin-Gemisch) und endlich nicht sehr erhebliche Mengen ziemlich kompressionsfesten Braunkohlenschwelbenzins verbraucht wurden.

Unter diesen Verhältnissen hat sich in Deutschland eine Vielgestaltigkeit der Fahrzeuge in Bezug auf ihr Verdichtungsverhältnis entwickelt. Das allgemeine Niveau des Verdichtungsverhältnisses dürfte wegen Deutschlands Reichtum an kompressionsfesten Kraftstoffen höher liegen, als in anderen Ländern. Im Einzelnen pflegt man in Deutschland Personenwagen verhältnismässig niedrig (1 : 4,5 bis 1 : 5) zu verdichten, während Personenfahrzeuge für Sportzwecke natürlich sehr hoch, aber auch Lastkraftwagenmotoren

ganz bemerkenswert hoch (z.B. Krupp 1 : 6, Henschel 1 : 5 bis 1 : 8) verdichtet werden.

Unwesentliche Eigenschaften der Kraftstoffe.—Handel und Verbrauch legen auf einzelne Eigenschaften Wert, welche in Wirklichkeit bedeutungslos sind oder andere Bedeutung haben als ihnen zugeschrieben wird.

(*a*) *Spezifisches Gewicht.*—Aus der Jugendzeit der Erdölindustrie pflegt man stellenweise immer noch die Leichtflüchtigkeit eines Kraftstoffs nach dem spez. Gewicht zu beurteilen und anzunehmen, dass ein niedriges spezifisches Gewicht Leichtflüchtigkeit verbürge, Derartige Zusammenhänge bestehen nur bei Benzinen aus gleichartigen Rohstoffen und auch dann nur unter besonderen Voraussetzungen. Praktisch kann man—angesichts der Crackbenzine, der Vielgestaltigkeit der Herkunft der Benzine, der Gewohnheit des Benzolbeimischens—aus dem spezifischen Gewicht heute gar keinen Rückschluss auf die Flüchtigkeit ziehen. Die Flüchtigkeit lässt sich nur durch den direkten Versuch bestimmen.

Im übrigen ist das spezifische Gewicht natürlich eine wertvolle Konstante. Je höher das spezifische Gewicht bei gleicher Flüchtigkeit, umso grösser im allgemeinen die Kilometerausbeute je Liter und die Kompressionsfestigkeit.

(*b*) *Farbe.*—Man verlangt von den leichtflüchtigen Kraftstoffen, dass sie farblos seien. Es ist richtig, dass Farblosigkeit auf gute Raffination schliessen lässt und die Beurteilung der Klarheit (Schmutz- und Wasserfreiheit) erleichtert. Schwach gelbe Färbung tritt aber praktisch sehr leicht ohne den geringsten Schaden für die Hochwertigkeit des Kraftstoffs ein, während umgekehrt vollkommen farblose Kraftstoffe qualitativ minderwertig sein können. Es dürfte sich deshalb empfehlen, auch bei leichtflüchtigen Kraftstoffen der Farbe weniger Gewicht beizulegen, zumal auch absichtliche Färbung vorkommt (z.B. Ethylgas, denaturierter Spiritus).

(*c*) *Lichtbeständigkeit.*—Alle Kraftstoffe verändern sich bei starker und dauernder Belichtung allmählich, die farblosen unter allmählicher Verfärbung. Manche Kraftstoffe zeigen rasche Verfärbung, Trübung, Abscheidung unlöslicher Bestandteile (manche Benzine und Benzole). Diese Lichtempfindlichkeit ist praktisch ohne Belang, weil Kraftstoffe ja in lichtundurchlässigen Behältern verwendet werden, sodass z.B. sogar ausgesprochen lichtempfindliche Kraftstoffe, wie mit Eisenkarbonyl versetztes Benzin (Motalin), praktisch keine Schwierigkeiten machen. Auch der Schluss von der Lichtbeständigkeit auf die Lagerbeständigkeit ist

keineswegs sicher. Es dürfte sich deshalb empfehlen, auf die Lichtbeständigkeit—abgesehen von analytischen Zwecken—keinen Wert mehr zu legen.

Massgebende Eigenschaften der Kraftstoffe.—Die drei massgebenden Eigenschaften der flüssigen Kraftstoffe sind:

(*a*) Flüchtigkeit,
(*b*) Reinheit,
(*c*) Verbrennungscharakter.

(*a*) *Flüchtigkeit.*—Bei der Flüchtigkeit ist zu unterscheiden zwischen der allgemeinen Lage der Siedekurve, wie sie durch die mittlere Siedetemperatur oder Kennziffer dargestellt wird, und zwischen der besonderen Gestalt der Siedekurve, die bezüglich der Neigung durch die mittlere Steigung (Fraktionierungsziffer), im Einzelnen aber nur durch die Siedekurve selbst angegeben wird. Ueblich ist es, den Siedebeginn, einzelne Punkte (v.H. Ueberdestilliertes bei 100 Grad C, 120 bezw. 130 oder 140 Grad C, bei 150 Grad C, bei 190 bezw. 200 Grad C und den 95 v.H.-Punkt bezw. den Endpunkt) anzugeben, bei höher siedenden Kraftstoffen noch andere Punkte. Die Siedekurve ist keine Konstante, sondern von der benutzten Apparatur abhängig. Für Benzin sind genormte Apparate nach Engler-Ubbelohde, für Benzol und Benzolgemische nach Krämer-Spilker üblich. Der Siedeendpunkt ist wenig sicher, weswegen der 95 Grad C-Punkt vorzuziehen ist. Bei leichtsiedenden Benzinen ist Verstärkung der üblichen Wasserkühlung zur Kondensation der sehr leichtflüchtigen Bestandteile ("Gasbenzin") nötig.

Nach der Höhenlage der Siedekurve kann man unterscheiden:

A. bis KZ 125 Grad C: Autokraftstoffe,
B. bis KZ 135 Grad C: Schwerbenzine,
C. bis KZ 200 Grad C: Motorenpetroleum,
D. bis KZ 275 Grad C: Dieselöl.

Da die Verdampfungswärme bei Benzol ein wenig, bei Alkoholen erheblich grösser ist, als bei Benzinkohlenwasserstoffen, wirkt sich bei diesen Kraftstoffen die theoretische Flüchtigkeit praktisch entsprechend schwächer aus.

Die Steigung der Siedekurve (Fraktionierungsziffer) nimmt in folgender Reihenfolge zu:

Alkohole und Alkoholgemische,
Benzol,
Benzolgemische.
Benzin,

Schwerbenzin,
Motorpetroleum,
Gasöl.

Je grösser die Steigung der Siedekurve, umso grösser pflegt die Neigung zu unvollständiger Verbrennung zu sein.

Im Einzelnen pflegen die Siedekurven S-förmig gekrümmt zu sein. Nicht zu magere "Vorderschwänze" sind bei leichtflüchtigen Kraftstoffen erwünscht zur Erleichterung des Anlassens. Magere hintere "Siedeschwänze" sind unerwünscht wegen der Gefahr unvollständiger Verbrennung und Oelverdünnung. "Sprünge" in der Siedekurve sind unerwünscht wegen Neigung zu unvollständiger Verbrennung.

Starker Gehalt an sehr leichtsiedenden Bestandteilen (Gasbenzin) ist unerwünscht, weil sie in warmen Kraftstoffleitungen, Vergasern usw. zu Dampfblasenbildung und dadurch zu Störungen führen, auch die Feuersgefahr erhöhen.

Siedekurven von Kohlenwasserstoffkraftstoffen können bezüglich des praktischen Verhaltens im Motor nicht ohne weiteres mit Siedekurven von alkoholhaltigen Kraftstoffen verglichen werden.

Auch bei Dieselölen ist verhältnismässig niedriges Sieden erwünscht, obwohl die Selbstzündungstemperatur für höhersiedende Kohlenwasserstoffe sinkt, weil niedriger siedende Oele weniger zu unvollständiger Verbrennung neigen.

(*b*) *Reinheit.*—Abgesehen von physikalischer Reinheit verlangt man chemische Reinheit der Kraftstoffe hinsichtlich ihres Schwefelgehaltes und hinsichtlich ihrer Neigung zu Ansaugventilverpichungen. Kleiner Schwefelgehalt ist unschädlich, sofern nicht eine Schwefelform vorliegt, die Metalle korrodiert. Grösserer Schwefelgehalt kann durch die bei der Verbrennung entstehende schweflige Säure unter (seltenen) Umständen Verrosten der Auspuffventile bewirken. Mehr fürchtet man aber die Akkumulierung von schwefliger Säure bezw. Schwefelsäure in dem Wasser, das sich aus Verbrennungsgasen gelegentlich im Kurbelgehäuse niederschlägt. Hierdurch können Anfressungen entstehen.

Ansaugventilverpichungen werden durch Kraftstoffe bewirkt, welche harzähnliche Stoffe entweder fertig gelöst enthalten oder bilden. Meist rühren solche Fehler von mangelhafter Raffination her. Der Schwefelsäuretest gibt einen Anhalt, die Rückstandbestimmungen auf der Glasschale einen weiteren. Ganz zuverlässig ist aber nur der Motorversuch.

(c) *Verbrennungscharakter.*—Bezüglich des Verbrennungscharakters kann man unterscheiden zwischen der Neigung zur Russbildung und der Neigung zum Klopfen.

Die grössere oder geringere Neigung zur Russbildung geht gleichsinnig mit einem grösseren oder kleineren H/C-Verhältnis. Chemisch reines Benzol beispielsweise neigt stark zum Russen (H/C-Verhältnis 1,0), Motorenbenzol vom B.V.-Typ (bei dem durch Homologenzusatz das H/C-Verhältnis auf etwa 1,50 heraufgesetzt ist) hat diese Neigung verloren, Benzin mit dem H/C-Verhältnis 2,1 ist nur sehr schwer zum Russen im Motor zu bringen. Aehnliches gilt für die Neigung zum Russen der höher siedenden Oele im Dieselmotor.

Eine Ausnahme machen die sauerstoffhaltigen (alkoholhaltigen) Kraftstoffe, welche überaus russfreie Verbrennung zeigen, ebenso wie Zuführung von Wasser zur Verbrennung die Russbildung verringert.

Die Neigung zum Klopfen im Zündermotor geht im allgemeinen parallel mit dem H/C-Verhältnis. Jedoch besteht die Besonderheit, dass bei Benzinen Erhöhung des Siedepunktes die Klopfneigung verstärkt. OH-Gruppen und Gegenwart von Wasser wirken klopfhindernd, ebenso bekanntlich aus noch nicht sicher erforschten Gründen organische Amine, bestimmte organische Metallverbindungen (Eisenkarbonyl, Tetraäthylblei usw.), während manche andere organische Verbindungen (z.B. Isopropylnitrit) klopffördernd wirken.

Im Dieselmotor klopfen umgekehrt die wasserstoffarmen Benzole und Steinkohlenteeröle leicht (wahrscheinlich wegen grösseren Zündverzugs und dadurch bewirkter Akkumulation der Verbrennung). Durch "Zündöltropfen," d.h. kleine Mengen wasserstoffreicher (im Zündermotor klopfender) Kraftstoffe kann man dieses Klopfen verhindern.

Die Messung der Neigung eines Kraftstoffs zum Klopfen ist nach mehreren Methoden (Variokompressor. Mischungsmethode) möglich. Es wäre wichtig international Masseinheit und Bezugspunkte festzulegen.

Die Kompressionsfestigkeit der leichtflüchtigen Kraftstoffe ist für den Zündermotor von grösster Bedeutung, weil grosse Kompressionsfestigkeit ein hohes Verdichtungsverhältnis und dadurch grosse Literleistung und grosse Wirtschaftlichkeit ermöglicht.

Es ist möglich, dass die Kompressionsfestigkeit eine ähnliche (umgekehrtes Vorzeichen) Bedeutung für Dieselöle bekommt,

nachdem die Bestimmung der Selbstentzündungstemperatur allein nicht auszureichen scheint.

Erfüllung der Anforderungen durch die Oelindustrie. Die Kraftstoffe für den deutschen Verkehr werden geliefert.

(*a*) Benzin von der ausländischen Erdölindustrie (Hauptmenge)
von der inländischen Erdölindustrie (unbedeutend)
von der deutschen chemischen Industrie (Synthese)
von der deutschen Braunkohlenindustrie (Braunkohlenbenzin).

(*b*) Benzol von der deutschen Steinkohlenindustrie (Hauptmenge)
von der ausländischen Steinkohlenindustrie (Nebenmenge).

(*c*) Alkohole von der Kartoffelbrennerei (Aethylalkohol)
von der chemischen und Papierindustrie (aus Sulfitablauge, Holz usw. ; Aethylalkohol)
von der chemischen Industrie (synthet. Methanol).

Im praktischen Gebrauch sind :

(*A*) Autobenzin (KZ ca. 120, Kompressionsfestigkeit gering, Hauptmarken Dapolin und Stellin),

(*B*) Motorenbenzol (KZ 100, Kompressionsfestigkeit sehr gross, fast ausschliesslich B.V.-Typ, genormt),

(*C*) Motalin (durch Eisenkarbonyl in seiner Kompressionsfestigkeit erhöhtes Benzin),

(*D*) synthetisches Benzin (in seinen Eigenschaften von Naturbenzin nicht zu unterscheiden; wird bisher als synthetisch noch nicht gekennzeichnet),

(*E*) Braunkohlenbenzin (verhältnismässig sehr kompressionsfest),

(*F*) Monopolin (früher Gemisch aus Benzin, Benzol und 95 %igem Spiritus, jetzt zunehmend Gemisch aus absolutem Alkohol und Benzin),

(*G*) Rennmotalin und Monopolin R (methanolhaltige Gemische für Rennzwecke)

(*H*) Benzin-Benzol-Gemische (meist etwa halb und halb aus Autobenzin und Benzol vom B.V.-Typ, verbreitetstes fertiges Gemisch ist B.V.-Aral.)

Während hiernach für die leichtflüchtigen Kraftstoffe sich sehr bestimmte Beschaffenheiten ausgebildet haben, werden für den

Dieselbetrieb sehr verschiedene Erzeugnisse von wasserhell raffiniertem Petroleum bis zu dunklem hochsiedendem Gasöl verwendet. Hauptlieferant ist die Erdölindustrie. Doch wird auch viel Braunkohlenteeröl und einiges Steinkohlenteeröl benutzt.

Es erscheint möglich und dringend wünschenswert, die Mannigfaltigkeit der Kraftstoffe auf einige wenige Typen zu verringern und für diese Normen auszuarbeiten. Für das Motorenbenzol ist dies bereits mit bestem Erfolge durch den Benzol-Verband geschehen. Eine solche Normung würde grosse Vorteile nicht nur für den Motorkonstrukteur und Verbraucher, sondern auch für Erzeuger und Händler mit sich bringen.

Deutschlands Kraftstoffdecke befindet sich in einem Zustande starker Aenderungen.

Einmal nimmt Deutschlands Kraftstoffbedarf stark zu. Der Jahresverbrauch für 1926 betrug etwa 600 000 tons, derjenige für 1927 liegt zwischen 820 000 und 900 000 tons. Für 1928 rechnet man mit einem Bedarf von annähernd 1 Million tons entsprechend der auch in Deutschland steigenden Kraftfahrzeugdichte und entsprechend der auch in Deutschland zunehmenden Benutzungsstärke des einzelnen Fahrzeugs.

Einen verhältnismässig konstant bleibenden Teil der deutschen Kraftstoffdecke stellt die deutsche Benzolerzeugung von etwa 280 000 tons im Jahr dar. Ihr gesellt sich als weitere deutsche Inlandserzeugung das synthetische Benzin der I.G.Farbenindustrie in steigendem, mengenmässig aber noch unbekanntem Umfange bei. Weitere deutsche Kraftstoffe, welche aber in grösserem Umfange nicht in Betracht kommen dürften, sind das Braunkohlenschwelbenzin, sind der Spiritus und sind die aus hannoverschem Erdöl gewonnene Benzinmenge. Der Rest wird durch Einfuhr ausländischen Benzins gedeckt, welche in der Hauptsache in den Händen der D.A.P.G. (Standard), der Rhenania (Shell) und der Russischen Importgesellschaft liegt. Es kommt neuerdings hinzu eine ausländische insbesondere amerikanische Einfuhr von Benzol. Der Benzoleinfuhrüberschuss betrug im Jahre 1927 nicht weniger als 114 000 tons.

Deutschland ist hiernach in der Lage, aus einheimischer Erzeugung etwa 50% seines Bedarfs zu decken. Da synthetisches Benzin aus in Deutschland reichlich vorhandenen Rohstoffen herstellbar ist, besteht die Möglichkeit für Deutschland, seinen Benzinbedarf ganz durch einheimische Erzeugung zu decken. Ob zu diesem Zweck der Ausbau von Kunstbenzinfabriken derart beschleunigt

wird, dass die Kunstbenzinerzeugung die Steigerung des Verbrauchs überholt, steht dahin.

Bei dieser Sachlage liegt es im deutschen Interesse. den spezifischen Verbrauch der Motoren so niedrig wie möglich zu halten. Aus diesem Grunde sind die deutschen Bestrebungen zur Erhöhung der Kompressionsfestigkeit der Kraftstoffe und zum Hochhalten des Verdichtungsverhältnisses der Motoren besonders lebhaft. Bei Deutschlands verhältnismässigem Reichtum an Benzol und bei der in Deutschland bestehenden Möglichkeit, ausreichende Mengen von Eisenkarbonyl herzustellen, würde man bei entsprechender Organisation des deutschen Kraftstoffverbrauchs ganz Deutschland mit kompressionsfesten Kraftstoffen beliefern und in Deutschland ganz allgemein das Verdichtungsverhältnis unter Verringerung des spezifischen Kraftstoffverbrauchs der Motoren steigern können. Diese Möglichkeit erscheint umso interessanter und dringlicher, als im internationalen Automobilmotorbau die Zweckmässigkeit der höheren Verdichtung heute allgemein anerkannt ist und international eifrig daran gearbeitet wird, durch konstruktive Mittel (z.B. Ricardo' scher Verbrennungsraum, Dumanois-Stufenkolben usw.) die Ansprüche hochverdichtender Motoren an die Kompressionsfestigkeit der Kraftstoffe zu verringern, wie gleichzeitig durch chemische Mittel (Ethyl, Eisenkarbonyl, Tetraäthylblei, Alkoholzusatz, sinngemässe Leitung der Crackverfahren usf.) die Kompressionsfestigkeit der Kraftstoffe selbst zu steigern.

THESEN

1. Die Anforderungen an die Kraftstoffe haben sich so klar entwickelt, dass es möglich erscheint, international eine verhältnismässig geringe Anzahl von Kraftstofftypen zu vereinbaren und deren wesentliche Eigenschaften zu normen.

2. Als Kraftstofftypen werden vorgeschlagen:
   (*a*) *leichtflüchtige Kraftstoffe* (*Autokraftstoffe*)
      (1) nicht kompressionsfest,
      (2) mässig kompressionsfest,
      (3) sehr kompressionsfest,
   (*b*) *mittelflüchtiger Sonderkraftstoff für die Luftfahrt*
   (*c*) *schwerflüchtige Kraftstoffe* (*Dieselöle*)
      (1) relativ niedrig siedend,
      (2) hochsiedend.

3. Zur Normung werden folgende Eigenschaften vorgeschlagen:
   (*a*) Flüchtigkeit (Kennziffer, Fraktionierungsziffer),
   (*b*) Reinheit,

(*c*) Kompressionsfestigkeit (Bezugspunkte und Mass noch zu bestimmen),
(*d*) Lagerbeständigkeit.
(*e*) Korrosionsfreiheit,
(*f*) Schwefelgehalt,
(*g*) H/C-Verhältnis,
(*h*) Geruch,
(*i*) Kältefestigkeit.

ZUSAMMENFASSUNG.—Der Motor des Kraftfahrzeugs ist eine sehr empfindliche Feuerung. Die Entwicklung in Deutschland geht dahin, qualitativ hochwertige, gut raffinierte und verhältnismässig niedrigsiedende Kraftstoffe zu verwenden. Die Ersparnis an Betriebskosten, welche durch billigere (z.B. höher siedende oder mangelhaft raffinierte) Kraftstoffe erzielt werden kann, steht ausser Verhältnis zu der so erzielten Erschwerung der Bedienung, Vergrösserung der Abnutzung, Verringerung der Betriebssicherheit und Wahrscheinlichkeit teurer Reparaturen.

Die in Deutschland an einem Kraftstoff (Motorenbenzol) erstmalig durchgeführte scharfe Normung hat sich in der Automobilpraxis vortrefflich bewährt. Normung aller Kraftstoffe in Bezug auf die wichtigsten Eigenschaften wird deshalb angestrebt.

Deutschland hat 1927 einen Kraftstoffverbrauch von etwa 820 000 tons gehabt. Im gleichen Jahre hat Deutschland 280 000 tons Benzol erzeugt und ausserdem einen Einfuhrüberschuss an Benzol von 114 000 tons gehabt. Der Rest des Bedarfs wurde in der Hauptsache durch ausländisches Benzin und nur zum kleinen Teil durch einheimisches Benzin (künstliches und natürliches), einheimisches Braunkohlenbenzin und einheimischen Alkohol gedeckt.

Für 1928 wird ein Bedarf von etwa 1 Million tons erwartet, von dem wiederum etwa 280 000 tons durch einheimisches Benzol und ein noch unbekannter Betrag durch synthetisches Benzin gedeckt werden wird.

In Deutschland liegt insbesondere bei Lastkraftwagen das Verdichtungsverhältnis höher als anderwärts, wodurch sich besonders sparsamer Kraftstoffverbrauch ergibt. Deutschland hat durch seinen Benzolreichtum, ferner durch Alkohol und Braunkohlenbenzin, sowie endlich durch Eisenkarbonyl die Möglichkeit, sein durchschnittliches Verdichtungsverhältnis noch weiter zu steigern, wenn die Kraftstoffindustrie geeignete organisatorische Massnahmen trifft.

PROPERTIES REQUIRED OF LIQUID FUELS FOR USE IN AUTOMOBILE AND AIRCRAFT ENGINES, AND HOW THE OIL INDUSTRY MEETS THESE REQUIREMENTS

WA. OSTWALD

(*English Version—Abridged*)

General

At the present time the substances employed as fuels for internal combustion engines include hydrocarbons, alcohols and certain organic compounds. As these substances only supply their energy indirectly, that is, by the change in volume which occurs when they are burnt, the relative value of a fuel must be determined by its calorific value, which itself is dependent on

(*a*) The carbon content,

(*b*) The hydrogen content,

(*c*) The oxygen content in the sense that the presence of oxygen represents partial combustion and reduces the calorific value,

(*d*) The form in which these elements are combined, *viz.*, aliphatic hydrocarbons have a lower calorific value than, for example, benzol or acetylene, and

(*e*) The impurities present. (The calorific value of sulphur is determined by the manner in which it is combined, while inorganic matter—ash—reduces the calorific value in the proportion in which it is present.)

Knowing the proportions in which the various constituents are present, it is, therefore, not possible to calculate exactly the calorific value of the fuel.

In general, the smaller the weight of fuel necessary to produce a definite amount of heat, the better the fuel. This can be seen from Table I., in which the weight (in grams) necessary to produce 1,000 *k* cals. is given for several fuels.

TABLE I.

Benzine	95
Benzol	104
Spirit	165
Methanol	214

As, in order to ensure greater freedom of motion and a larger sphere of action, mechanical transport units must carry their source of power, this "energy-weight" is of considerable importance. A more convenient method of expressing the value of a fuel, however, is by means of the "energy-volume," that is the volume of fuel required to furnish a definite amount of energy. In Table II. the volumes in (cubic centimetres) required to give 1,000 *k* cals. are shown.

TABLE II.

Benzine	127
Benzol	119
Spirit	204
Methanol	271

This value is particularly useful, for by means of it the radius of action of a motor vehicle can be estimated from its tank capacity.

As fuels are sold by volume, the price of a fuel per unit of energy can be calculated from the "energy volume." Actually, *ceteris paribus*, this

"energy-price" forms a useful basis for the evaluation of a fuel, although it varies with the state of the market.

The "energy-price" of low-boiling fuels such as benzine is very much higher than that of the high-boiling or heavy fuels—an incentive to the chemist to produce high "energy-price" fuels from the cheaper, heavier raw materials.

Apart from the fuel itself, oxygen must also be considered as an energy-bearer and taken into account. Under normal conditions there is no need to consider it except as a basis when studying the effect it produces at other pressures. Although it cannot alter the calorific value of fuel, at low pressures, *e.g.*, at great heights, it affects the compression and carburation systems. So far (in spite of the five-fold power volume ratio it affords) pure oxygen has not been used for internal combustion engines on account of the high temperatures produced and other technical difficulties.

The essential features of a fuel for automotive engines are low cost and high ton-mileage, and, to secure the former, thermal efficiency is often sacrificed. The wide range of uses to which such fuels are put, from driving private cars to driving lorries or fishing boats, indicates that two types of fuel are really necessary, one a " luxury" fuel and the other a "useful" fuel. While the chief requirements of the former include easy starting, rapid acceleration, clean burning and absence of odour both before and after combustion, those of the latter are cheapness and high ton-mileage. The cost of the "luxury" fuel must, on account of the extra cost of production, be higher than that of the "useful" fuel.

Between the engine designer and the fuel chemist two classes of fuels have been developed. Although differing considerably in boiling range, these fuels are essentially the same. One is low-boiling and is used in the constant-volume cycle engine, while the other boils over a very much higher range and is employed in Diesel engines. At present, the lighter of the two fuels is the less economical.

Fuel development and engine design have influenced each other. For example, the constant-volume cycle engine has been improved by increasing the compression ratio, this being rendered possible by the production of fuels stable to high compression, such as aromatic, naphthenic or alcoholic fuels. "Anti-knocking" agents have also been developed for increasing the stability of fuels towards high compression. On the other hand, the advent of the high speed Diesel engine has resulted in lower compression ratios being used and also in a considerable decrease in engine weight. For this type of engine, the aliphatic fuels are preferred, on account of their low spontaneous ignition temperatures or "pro-knocking" tendencies.

The need for a heavy oil carburetting system for airship and aeroplane use will exist until a light Diesel engine is available, owing to the particular risk of fire on aircraft. The care taken of aero engines and the steady output required of them are both factors in favour of the development of this type of engine. It would, therefore, seem worth while examining the behaviour of a close cut hydrocarbon fuel, boiling at approximately 180°C. (which would lessen the risk of fire) in a carburetting system.

GENERAL PROPERTIES OF LIQUID FUELS

Corrosive Action

Copper, lead, zinc, aluminium, magnesium and their alloys are all employed

in the fuel systems of automotive engines. All are liable to be corroded by the fuel and, unless precautions are taken, this corrosion may become so serious that the pipes of the fuel system become choked. The causes of the corrosive action are acid remaining from the refining, free and combined sulphur (sulphur in thiophene, carbon disulphide, etc., is not corrosive), aromatic hydroxyl compounds, such as phenols or naphthenic acids, and unknown compounds resulting from poor refining.

Sulphur is particularly corrosive towards brass and copper; tin, on the other hand, is immune from all the corrosive agents mentioned and can be used to protect tubes, etc. Until all fuel systems are protected by tinning, however, the fuel must be non-corrosive.

The corrosive action of a spirit is tested by observing its action on strips of various metals placed in it.

Stability

It is essential that a fuel should stand storage for at least six months without alteration in closed tanks, whether galvanised, lead-coated or not.

The risk of alteration is particularly great for badly refined low boiling spirits which leave a residue on evaporation. The test for stability is to evaporate 100 c.c. of a six months old specimen on the water bath; not more than 50 mgm. of residue should remain.

Freedom from Dirt and Water

Notwithstanding the fact that fuel systems on all engines are fitted with devices for separating water and dirt, motor fuels must be perfectly clean on account of the great sensitivity of the carburettor and fuel pumps to these impurities. Water and dirt, with rare exceptions, separate out on standing, so that dirt separation must rest rather with the carburetting system than with the fuel. As rust formation and water separation are practically unavoidable (both benzine and benzol dissolve small amounts of water), suitable devices must be fitted to deal with them. Alcohol mixtures deposit no water but the dirt chokes the filter so that special care is necessary in designing suitable cleaning devices for these fuels.

Odour

Certain fuels have a pronounced odour which is objectionable to many people. This applies not only to the fuel itself, when an unpleasant odour is usually due to poor refining, but also to products produced by incomplete combustion due to over-rich mixture or other causes. For example, partially-burnt tetralin affects the eyes and has an unpleasant odour, while benzines with heavy "tails," many cracked benzines and low boiling lignite distillates, all tend to burn badly and impart a penetrating and objectionable odour to the exhaust. The exhaust gases from Diesel engines running on gas oils have an irritating effect on the mucous membrane owing to the presence of traces of some product resulting from incomplete combustion, a nuisance which can be overcome by injecting water or alcohol into the cylinder with the fuel, or better by ensuring complete combustion, as in the Junkers opposed piston engines. Unless steps are taken the unpleasant odour may inconvenience passengers or contaminate delicate goods such as food, while the exhaust gases pollute the street air.

Toxicity

All low boiling fuels in the form of their vapours exert a suffocating effect

on animal life. In smaller concentrations the effect is narcotic; the order of their activity is benzine, benzol and alcohol.

On the other hand, exhaust gases are poisonous owing to the presence of carbon monoxide, again resulting from incomplete combustion. As indicated above the presence of alcohol in the fuel promotes combustion while high boiling "tails" and high carbon contents favour incomplete combustion. Attempts to overcome these effects have been made by the use of a catalytic process of after-burning, but apparently so far with little success.

The presence of lead tetraethyl in the fuel renders it toxic and such fuels are, therefore, coloured red to avoid mistakes being made. When using lead-doped fuels, separation of lead in the engine and pollution of the street air are unavoidable. Owing to medical assertions that lead poisoning is cumulative, the introduction of lead tetraethyl into Germany would be difficult. A further reason for this is its technical inferiority to iron carbonyl; and so no inconvenience is caused.

Skin Irritation

Motor fuels act on the skin by dissolving out the fat, which, in the case of certain individuals, gives rise to skin irritation. Benzine and gas oil give little trouble in this respect, but coal tar oils and tetralin are particularly potent and cause inflammation or eczema.

Tendency to Dissolve Varnish, etc.

The varnishes of the linseed oil type, which it is customary to employ on automotive engines, are generally little affected by benzine or gas oil although more so by benzol and coal tar oils; they are, however, readily attacked by alcoholic mixtures, tetralin, etc. The same applies in a lesser degree to the cellulose paints, although for all practical purposes these remain unattacked. Until, however, the use of cellulose lacquers becomes general, attention must be paid to the solvent action of fuels on varnishes.

Miscibility

Hydrocarbon fuels, *i.e.*, benzine, benzol, gas oil, coal tar oils, lignite oils, etc., are miscible in all proportions *inter se*. Anhydrous (absolute) alcohol is also completely miscible with hydrocarbon fuels but this property disappears on the addition of water, for example, by absorption from the atmosphere. It is, therefore, necessary to add certain substances such as hydrogenated phenols or higher alcohols which have the property of rendering aqueous alcohol and benzine miscible, to prevent separation occurring. These substances are known as "Homogenisers."

Stability at Low Temperatures

Fuels intended for automotive engines must show no tendency to solidify or separate into their constituents when cooled to -15 to -25°C., while aircraft fuels must stand much more rigorous cooling without alteration. Benzine is completely unaffected by cooling while gas oil shows only an increased viscosity. On the other hand, coal tar distillates tend to solidify through the separation of naphthalene, etc., and benzol itself freezes at -4°C. The freezing point of the latter substance is considerably lowered by the presence of its homologues (B.V. type) although benzol tends to separate out at -15°C. Alcohol and benzine produce a still more marked effect on its freezing point. Alcohol alone or mixed with hydrocarbons, can be cooled to extremely low temperatures without change, but the presence of a little

water renders alcohol-hydrocarbon fuels very sensitive to cooling. Benzine-alcohol mixtures are much more sensitive than the corresponding benzol-alcohol fuels. This sensitivity is reduced by the so-called "Homogenisers" (*vide supra*).

Sensitivity to Water

Benzine is capable of dissolving a small quantity of water, the amount increasing with rise in temperature. The same holds to a greater extent for benzol, with the result that if benzol saturated with water is mixed with benzine, water at once separates. In practice, the separated water tends to collect impurities present in suspension such as rust, etc. These accumulate at the boundary between the two layers, a circumstance which allows the dirt to be drawn off with the water in the form of a sludge. Alcohol mixtures may dissolve several per cent. of water with the result that eventually separation into two layers occurs. The number of cubic centimetres of water which causes permanent turbidity in 100 c.c. of an alcoholic fuel is a convenient means of estimating the content of water in the alcohol present.

Production and Supply of Fuels

The only fuels of use for the production of automotive power are (apart from certain exceptions) those without any great peculiarities. Exceptional fuels are only of value when sufficient supplies are available. An example of this is shown by benzol, which in Germany is so plentiful that it is used both alone and mixed with benzine; as a result German automobile engines tend to have comparatively high compression ratios. As, in the U.S.A., the total benzol production forms only a fraction of the motor fuel consumption, American car builders can only increase the compression ratio of their engines as better fuels become available.

Actually, Germany has a very large quantity of high-compression fuel for disposal. In 1927 the benzol production amounted to 300,000 tons, which with that imported, 114,000 tons, became 414,000 tons. Of this, only a small quantity was required for the chemical and rubber industries, etc., so that approximately 400,000 tons was available as fuel for motor engines. As the total German consumption for 1927 was 800,000–900,000 tons, this represents 50 per cent. of the total consumption and corresponds, when mixed with the benzine, with a 40–50 per cent. benzol mixture. Actually, in this particular year, a considerable portion remained unsold, for besides benzol, other high compression fuels such as "Motalin" (benzine "doped" with iron carbonyl), "Monopolin" (alcohol-benzine-benzol mixture) and lignite benzine were also available. The net result is that the compression ratios of German automobile engines are higher than elsewhere. For export the compression ratios must be lowered. The average compression ratio of private cars runs from 1 : 4·5 to 1 : 5, while for sports cars it is naturally very much higher. Certain lorries, *e.g.*, the Krupp (1 : 6) and the Henschel (1 : 5 to 1 : 8) also have high compression ratios.

UNIMPORTANT CHARACTERISTICS OF FUELS

Commercial users of motor fuels often place great value on properties which, in practice, are meaningless or misleading.

Specific Gravity

From an early date the petroleum industry has measured the volatility of a fuel by means of its gravity, a low specific gravity being taken to indicate high

volatility. This relationship only holds, however, when the benzines have been produced from similar crude oils and then only under special circumstances. In fact, owing to cracking and the many possible origins of the crude oil, no conclusions can safely be drawn from the specific gravity. Volatility can only be determined directly. Moreover, the specific gravity is an evaluation constant, for with fuels of equal volatility, the higher the gravity the better, and in general, the mileage and the compression stability also.

Colour

It is specified that volatile fuels must be colourless. While it is certainly true that colour usually indicates poor refining and turbidity the presence of dirt or water, a faint yellow colour, which is often found in practice, makes no difference whatever to the value of the fuel; colourless fuels are in fact often less valuable. No notice should, therefore, be taken of the colour of a motor fuel. Many are actually being tinted intentionally, *e.g.*, Ethyl gas or "Eno."

Stability to Light

All hydrocarbon fuels are affected by strong light with the result that they go "off colour." Many benzines and benzols become turbid and eventually an insoluble layer separates. As, however, fuels are never subjected to such drastic treatment in practice but are always stored in impenetrable containers, this test is unnecessarily severe. No difficulty has been experienced in the use of iron carbonyl which is actually decomposed by light. Again, the bearing of light-stability on storage-stability is not at all certain.

IMPORTANT CHARACTERISTICS OF FUELS

The three properties of a fuel which determine its value are : (*a*) Volatility, (*b*) purity and (*c*) combustion characteristics.

Volatility

By volatility one must differentiate between the general position of the distillation curve, which is given by the average distillation temperature or index temperature, and the shape of the curve with respect to the slope of the average gradient; the distillation curve is usually intended. It is customary to give the initial boiling point, the distillate (per cent.) at definite temperatures, for example, at 100°C., at 120°C., 130°C., or 140°C., at 150°C., at 190°C. or 200°C., the 95 per cent. distillate temperature and the final boiling point—further figures being given for higher boiling fuels. The distillation curve is not constant, however, and depends on the apparatus used. For benzine the Engler-Ubbelohde apparatus is used, while for benzols, Krämer and Spilker's apparatus is generally employed. As the final boiling point is not particularly accurate, the 95 per cent. temperature is preferred. When distilling light fuels, *e.g.*, natural gas gasoline, extra cooling is necessary for the condenser, to prevent losses.

According to the position of the distillation curve one can differentiate between various types of fuels.

(*A*) Up to an average distillation temperature of 125°C. : Motor spirit (gasoline).
(*B*) ,, ,, ,, ,, 135°C. : Heavy benzine (vaporising oil).
(*C*) ,, ,, ,, ,, 200°C. : Kerosene.
(*D*) ,, ,, ,, ,, 275°C. : Diesel oil.

Since the heat of vaporisation of benzine is smaller than that of benzol hydrocarbons while that of alcohols is very much higher, it follows that the volatility of these fuels should be correspondingly less.

The slope of the distillation curves is in the following order :

Alcohol and alcohol mixtures,
Benzol,
Benzol mixtures,
Benzine,
Heavy benzine,
Kerosene,
Gas oil.

The steeper the curve the greater is the tendency to give rise to incomplete combustion.

The absence of low boiling hydrocarbons is undesirable because difficulty is then experienced when starting, while heavy "tails" give rise to incomplete combustion and dilution of the lubricating oil ("crank-case dilution"). "Jumps" in the curve also tend to produce incomplete combustion.

Although the absence of volatile hydrocarbons gives difficult starting, too high a content (as in natural gas gasoline) gives trouble, because it vaporises in the warm fuel lines and produces "locks"; it also increases the danger of fire.

No inferences with respect to their behaviour in the engine can be drawn by comparing hydrocarbon distillation curves with those obtained from alcohol-hydrocarbon blends.

Low boiling constituents are also desired in Diesel oils for, although the higher the boiling point the lower the spontaneous ignition temperature, low boiling constituents give more complete combustion.

Purity

Apart from freedom from inorganic matter, etc., low sulphur and gum-content are also required. A small amount of sulphur in the oil, providing it is not present in a corrosive form, is not in any way injurious. A high sulphur content on the other hand may give trouble, the sulphurous acid, produced on combustion, corroding the exhaust valves. A much more serious danger is the accumulation of sulphurous or sulphuric acid in the water, usually found in the crank-case, producing corrosion.

Certain fuels containing dissolved gummy matter, or which form gum easily, tend to "gum-up" the inlet valves. This trouble in most cases is due to insufficient refining. Although the sulphuric acid test and the determination of the residue on evaporation both indicate the tendency to gum, in practice the engine test only is reliable.

Combustion Characteristics

When considering the combustion characteristics of a fuel, one must differentiate between the tendency to detonate and the tendency to form soot

The extent to which soot formation occurs is dependent upon the hydrogen-carbon ratio. For example, chemically pure benzol, H/C ratio = 1, shows a greater tendency to form soot than motor benzol (B.V. Type) in which, owing to the presence of homologues, the H/C ratio = ca. 1·5 while benzine, having a H/C ratio = 2·1, only forms s ot with great difficulty. The same holds true for the higher boiling oils employed for Diesel engines.

Fuels containing oxygen, *e.g.*, alcohol mixtures, burn exceptionally cleanly with absolutely no soot formation. Addition of water to hydrocarbon fuels produces a similar effect.

In general, the tendency of a fuel to detonate is also determined by the H/C ratio, although with benzines the tendency to "knock" increases with the boiling point. The presence of certain groups, such as —OH groups and water itself, reduce detonation. Other substances which tend to suppress "knocking" include certain aromatic amines and organo-metallic derivatives such as lead tetraethyl, iron carbonyl, etc. On the other hand, certain compounds, *e.g.*, *iso*-propyl nitrite, induce detonation.

The converse is true for Diesel fuels, fuels poor in hydrogen, such as benzol and coal tar distillates, knocking slightly; this is probably on account of the delay in ignition and the resulting accumulation of combustion. It can be prevented by introducing a small quantity of a fuel rich in hydrogen ("pro-knock" in constant-volume cycle engines) with the coal tar fuel.

Several methods have been devised for measuring the detonating tendencies of various fuels, but so far no international standard has been adopted.

The compression-stability of volatile fuels intended for constant-volume cycle engines is of considerable importance on account of the possiblity of using high compression ratios which give higher power output and are more economical.

Conversely, it is possible that compression-stability also has a bearing on the behaviour of Diesel oils, in an inverse sense, as the spontaneous ignition temperature alone does not appear to explain everything.

HOW THE OIL INDUSTRY MEETS THE REQUIREMENTS OF THE AUTOMOBILE ENGINE USERS

The fuel requirements of German motor transport, etc., are met as follows:

(1) Benzine. (*a*) From foreign petroleum (principal part).
(*b*) From home produced petroleum (insignificant).
(*c*) From chemical industry (synthesis).
(*d*) From lignite industry (lignite benzine).

(2) Benzol. (*a*) From home coal industry (principal part).
(*b*) From foreign coal industry (smaller part).

(3) Alcohols. (*a*) From potato fermentation (ethyl alcohol).
(*b*) From chemical and paper industry (from sulphite lye, wood, etc. ; ethyl alcohol).
(*c*) From chemical industry (synthetic methanol).

These are employed as follows :

A. Gasoline. (Average distillation temperature ca. 120°C. Anti-detonating value small: principal grades "Dapolin" and "Stellin.")

B. Benzol. (Average distillation temperature 100°C. Anti-detonating value very high, almost exclusively B.V.–Type.)

C. Motalin. (Benzine "doped" with iron carbonyl.)

D. Synthetic benzine. (Very similar to natural benzine; not yet characterised as synthetic.)

E. Lignite benzine. (Anti-detonating value high.)

F. Monopolin. (Formerly a mixture of benzine, benzol and 95 per cent. spirit, now an improved mixture of absolute alcohol and benzine.)

G. Racing monopolin and motalin. (Racing fuels containing ethanol and methanol.)

H. Benzine-benzol mixtures. (Mostly 50 : 50 mixtures of gasoline and benzol (B.V.–Type). The most widespread mixture is "B.V. Aral".)

Although only very definite products are used for motor engines, oils varying from water-white refined oils to heavy residues are employed for Diesel engines. These are chiefly provided by the petroleum industry but some lignite and coal tar distillates are also used.

A reduction in the number of fuels of different types is highly desirable, a smaller number of standard fuels being preferred. Motor benzol has already been standardised by the Benzol-Verband with great success. Standardisation of motor fuels offers many advantages, not only to the engine designer and the consumer but also to the producer and the dealer.

The fuel position in Germany is at present changing chiefly because the German fuel requirements have increased enormously. In 1926 the consumption amounted to 600,000 tons while that for 1927 was between 820,000 and 900,000 tons. It is estimated that the fuel consumption for 1928 will be over 1,000,000 tons as both the number of vehicles in use and the size of the individual power units are increasing.

At present, Germany is in a position to produce practically half her total consumption at home. It is quite possible that by developing the synthetic benzine industry she will become entirely self-supporting. Whether plant will be erected with this end in view remains to be seen.

Under the circumstances, it is in the German interest to reduce the fuel consumption as much as possible and considerable attention is, therefore, being paid to increasing the compression-stability of the fuels in order to raise the compression ratios of the engines.

The possibility of decreasing the fuel consumption appears so interesting and urgent a problem that motor builders all over the world generally acknowledge the necessity for high compression.

Attempts are being made to solve the problem by engine design (Ricardo's combustion chamber, the Dumanois' stepped piston, and so on) as well as by increasing the compression-stability of fuels through chemical means (iron carbonyl, lead tetraethyl, alcohol, development of cracking process, etc.).

PROPOSED SPECIFICATIONS

Fuel requirements have become so definite that it is possible to select a small number of fuels as standards and specify their essential characteristics.

The suggested fuels are :

(*A*) Fuels of high volatility. (Gasolines.)
- (1) Low anti-knock value.
- (2) Medium ,, ,,
- (3) High ,, ,,

(*B*) Special fuels of medium volatility for aircraft.

(*C*) Fuels of low volatility. (Diesel oils.)
- (1) Relatively low boiling range.
- (2) High boiling range.

The following properties to be standardised :

(*a*) Volatility. (Average boiling point, fractionation index.)
(*b*) Purity.
(*c*) Compression stability. (The standard and measurement to be specified.)
(*d*) Stability on storage.
(*e*) Freedom from corrosive action.
(*f*) Sulphur content.
(*g*) H/C ratio.
(*h*) Odour.
(*i*) Stability to cold.

RECENT DEVELOPMENTS IN THE DISTILLATION OF PETROLEUM

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS

DR. S. F. BIRCH AND DR. A. E. DUNSTAN

Paper No. F4

CONTENTS

THE MODERN PIPE-STILL—THE FRACTIONATION OF NATURAL GAS GASOLINE—THE DISTILLATION OF LUBRICATING OILS—ZUSAMMENFASSUNG

During many years the petroleum refining industry has been developing, step by step, from the old rule of thumb methods, and approximating steadily to a perfection of plant control that is only obtainable by accurate and scientific procedure. Early distillation plant consisted of flat-bottomed cheese-box stills and simple worm condensers. Frequent re-distillation was necessary, but there was little need for sharp fractionation, seeing that in the early days almost the only product was kerosene; gasoline being, in fact, an objectionable waste material, while at the heavier end lubricating oils derived from petroleum were as yet unknown. Step by step an increasing degree of fractionation became desirable, until to-day the perfection and efficiency long ago obtained in the alcohol industry have been attained in petroleum refineries, and the large area previously covered by primary stills and re-distillation units is now unnecessary, seeing that a simple equipment, consisting of a pipe still, fractionating column, heat exchangers and condenser, is sufficient. The pipe still, long known, in point of fact, in the coal tar industry, only really came into its own in the petroleum industry when the necessity for accurate control of heat, pressure, and velocity was demanded by the development of cracking.

THE MODERN PIPE-STILL

The modern pipe-still unit consists essentially of the following components :—(1) a furnace containing tubes through which the oil is passed under pressure; (2) a vaporising chamber or evaporator in which the oil is flashed, *i.e.*, the whole of the required distillates removed in one operation, the final residue being taken off at the bottom; (3) a fractionating column in which the vapours are fractionally condensed to give the desired products. Refinements usually incorporated include heat exchangers (from which, in some plants, it is actually possible to remove the lightest fraction) and automatic control devices; heat economy and a standardisation of working conditions, and, therefore, of products, are attained thereby. It is evident that the conditions of working may be so modified that only a part of the required distillates is removed in the above operations and that a second pipe-still, evaporator and column may then be employed to deal with the partial residue from the first. This process of dealing with the oil in two operations is known as the "double-flash" system as distinct from the "single-flash" system, in which all the required distillates are taken off in one operation. Up to the present the single-flash system is more widely employed, the double-flash method of working being less efficient.

As typical of modern pipe-still installations, the following description of the M. W. Kellogg Company's (New York) pipe still, which incorporates the Cross radiant heat recirculation type furnace, designed to handle 2,000 barrels of Roumanian crude oil per day, is of interest. The following products are obtained :—

TABLE I.

	% on crude by weight.	I.B.P. °C.	F.B.P. °C.	S.G.
Light gasoline	10	40°	110°	.720
Naphtha	4	105°	140°	.767
Light kerosene	17	135°	230°	.790
Heavy kerosene	10	220°	280°	.840
Gas oil	6	270°	340°	880
Fuel oil	52	—	—	.945
Loss	1			

The very low loss is not unusual in the most modern pipe-still installations and presents one of the many advantages over shell-still units. Although the above fractions were those for which the plant was specially designed, the flexibility is such that with the same apparatus other fractions could just as readily be obtained. For example, light and heavy kerosene could be taken

off together, whilst light gasoline and naphtha could be combined to give a single fraction consisting of gasoline of higher end point.

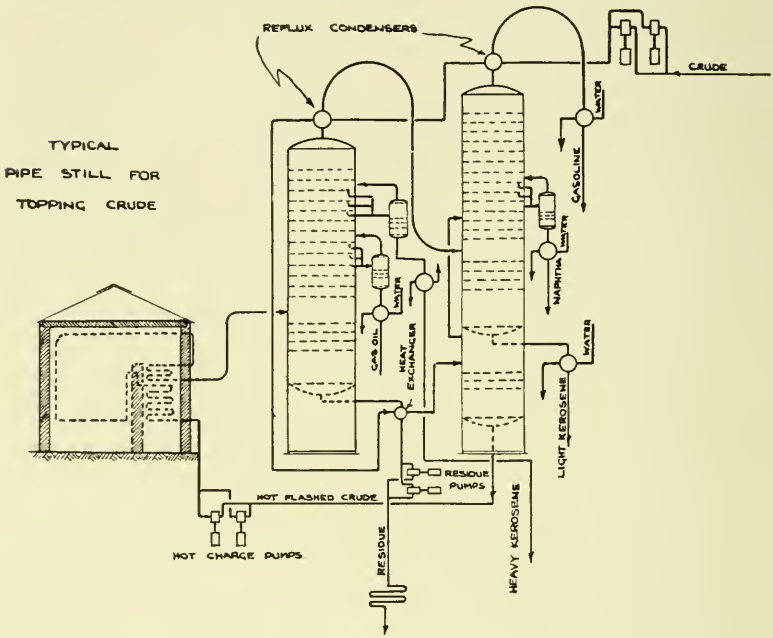


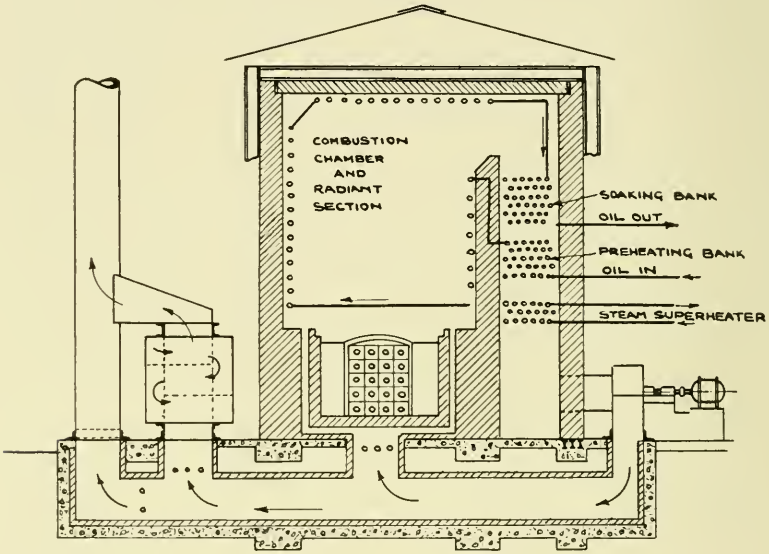
Fig. 1.

The flow of the oil through the plant is best illustrated by reference to Fig. 1. Cold oil is directed by means of the cold oil pump to the reflux condenser on No. 2 tower, where it is heated by the rising vapours, sufficient of which is thereby condensed to furnish the correct amount of reflux to give the required fractionation on this tower. It then passes to the reflux condenser on No. 1 tower, where it is still further heated to a temperature above 125°C., again supplying the necessary reflux. From this reflux condenser the crude oil is passed through the fuel oil heat exchanger, where the fuel oil is cooled approximately from 300° to 150°, the crude oil being further heated to about 200°C. in the process. The heated oil is now discharged into the flash tower, the temperature of which is so high that all permanent gases, together with some light gasoline and naphtha, are vaporised and taken to No. 2 tower, where they are mixed with vapour coming from No. 1 tower. The partially reduced crude oil, now at

roughly 175°C., is taken from the flash tower by the hot oil pump and charged to the furnace. From the furnace the oil is directed to the bubble tower evaporator, where all overhead products are "flashed"; the residual fuel oil, freed from lighter constituents, passes through the fuel oil heat exchanger to the fuel oil pump, which delivers it through an after-cooler to storage. The vapour in this tower passes up through the bubble decks and is fractionated in the process. Gas oil is the first to be condensed, being withdrawn from the proper deck into a stripping drum, in which it is stripped of lighter products by means of a small amount of waste steam, and from which it is withdrawn through the gas oil cooler to storage. Kerosene passes up through successive bubble decks, heavy kerosene being condensed and withdrawn from the appropriate deck, stripped by means of exhaust steam in a stripping drum and passed through the heavy kerosene cooler to storage. The residue vapour passes through the remaining decks and through the reflux condenser, where the proper amount of liquid is condensed to give the necessary reflux, the latter being dropped back into the tower to ensure fractionation and so maintain the end-point of the light kerosene. This tower is automatically controlled by means of an electrically-operated by-pass valve for the crude oil passing through the reflux condenser; it is sufficiently flexible to allow the specific gravity and boiling range of the kerosene and gas oil to be varied over a very wide range. From No. 2 tower gasoline is removed overhead, after being fractionated and passed to the condenser and thence to storage, whilst the naphtha is withdrawn in the liquid phase through a stripping drum, where light products are removed by means of exhaust steam and returned to the tower, the stripped naphtha being passed through the cooler to storage. The end-point of the light gasoline is regulated to the required temperature by means of the reflux condenser. The design of this tower permits a wide variation at will of the specific gravities and boiling ranges of the products; the bubble decks in the lower part of the tower ensure the removal of light products from the light kerosene.

The Cross radiant heat recirculation type furnace, incorporated in the Kellogg pipe-still unit, which is being described, is illustrated in Fig. 2. In order to avoid the harmful effect of high furnace temperatures on the oil, tubes, and brickwork, the usual practice has been to introduce an excess of air. This is necessarily extravagant, since the excess air must be pre-heated to the furnace

temperature, a process involving high fuel consumption. Even when the air is highly pre-heated the use of a large excess is both uneconomical and, owing to its oxidising effect, dangerous. In order to avoid the harmful effects of both excessive furnace temperatures and highly oxidising conditions, recirculation of flue gases and the use of radiant heat are becoming increasingly appreciated. Both these principles are incorporated in the design



SECTIONAL ELEVATION

RADIANT HEAT RECIRCULATED FLUE GAS FURNACE

FOR

2,000 BBL. PIPE STILL

Fig. 2.

of the furnace illustrated in Fig. 2, which is typical of the most modern pipe-still furnace construction. The tubes in the convection section are submitted to a very moderate temperature, obtained by mixing fresh products of combustion with gases which have already passed through the furnace. In the radiant section, whilst the flame temperature may be as high as 1,700 to 1,750°C., thus ensuring good combustion, the tubes are not subjected to direct heating by flame since the products of combustion

are taken to the combustion chamber through a number of openings along the walls, thus providing for the tubes a protective blanket, which is transparent to the radiation from the hot gases. This form of heating permits easy control and allows a high rate of heat transfer without danger of damage to the oil, the furnace tubes or the brickwork. Moreover, risk of local overheating of the oil with incipient cracking is further minimised since the oil introduced into the radiant section, where the furnace temperatures are highest, is still at a comparatively low temperature, having merely been pre-heated by contact with exhaust gases on their way to the flue. The oil passes at about 325°C. from the radiant section to the convection section, where the gas temperature does not exceed 700°C. Further provision against "skin-cracking" is thus afforded, and efficient heat transference to the oil is accomplished by gradual rather than by sudden heating. When the oil leaves the bank of tubes in the convection section it is at its maximum temperature.

It is of interest to note that while in the Cross furnace the tubes are protected by a blanket of recirculating gas, in the Foster tube still the tubes are encased in corrugated cast-iron tubes, which serve the same purpose as well as helping to absorb the radiant heat.

The furnace shown in Fig. 3 is described by Nash[1]; its action is clear from the diagram. Direction of the flame along a car-

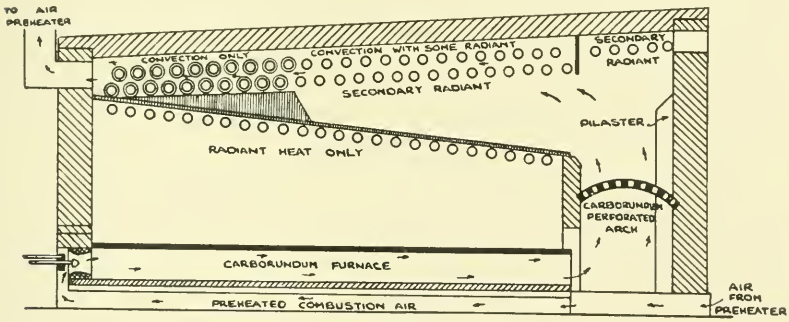


Fig. 3.

Reproduced by courtesy of "The Refiner."

borundum tunnel serves to heat still further the pre-heated incoming feed air, whilst the heat-conducting carborundum roof forms a highly efficient radiating surface.

Mekler[2] has indicated several ways in which furnace gases may be recirculated; it is evident that many variations are possible.

During the course of the development of modern pipe-still furnaces it has been found that suspension of the tubes by a structure independent of the furnace brickwork eliminates much of the trouble due to expansion strains, which are liable to cause cracking, with consequent air infiltration and loss of efficiency.

Evaporation

From the outlet of the pipe heater, the mixed oil and vapours are introduced into an evaporating chamber. Here we find a great many different types in service. Some are horizontal with longitudinal splash plates, some vertical with conical baffles. Others introduce the oil at a tangent in a vertical separator. Sometimes the stream is led directly into the fractionating column. All designs have some peculiar merit and are more or less efficient. The evaporator should spread the oil out in a film to allow plenty of disengaging surface and be of a size to give sufficient time for separation.

Whether the evaporator is part of the column or is separate, we have at its outlet the same conditions, namely, a large volume of vapour composed of all the overhead products. Upon their efficient separation into close commercial cuts depends the success of the distillation unit as a whole.

Dephlegmation

Modern equipment for fractionating petroleum has been evolved through various stages somewhat as follows :—

1. A dome on the still.
2. An enlarged vapour line.
3. Towers consisting of vertical enlarged pipes.
4. Unpacked vertical towers.
5. Packed towers with radiation from the shell to the atmosphere to provide reflux.
6. Baffle towers with aerial radiation.
7. Insulated baffle and tray towers cooled by discharging oil into the tower.
8. Bubble cap towers.

During the past ten or fifteen years the bubble cap tower, which has long formed part of the ordinary equipment for distilling alcohol or coal tar products, has gradually been modified to meet the special requirements of the petroleum industry. The factors

governing the design have been largely determined and a modern bubble cap tower is specially constructed for a specific and quite definite purpose. Thus the superficial velocity of vapour through the tower determines the diameter of the shell, the volume of the vapour determines the slot area of the bubble caps, the sharpness of fractionation required determines the number of decks, and so on.

Robinson,[3] dealing with a column into the central portion of which the liquid to be fractionated is introduced whilst steam is blown in at the base, makes the following generalisations :—

1. The function of the portion of the rectifying column above the feed plate is to remove the less volatile components, leaving the distillate composed of only the more volatile fractions.

2. The portion of the column below the feed plate serves to separate the more volatile fractions from the stream of the heavier fractions leaving the bottom of the column.

3. Heat must be supplied in the lower part of the column either as the latent heat of rising vapour or as heat from steam, and must be withdrawn from the upper part, usually by condensing part of the distillate, which may be by means of cold feed, low-boiling feed, or down-flowing feed. Any portion of the column below the point where heat is introduced or above that from which heat is abstracted is inoperative.

4. A single condenser at the top of a column with part of the condensate returned as reflux is more economical than more complicated condensing arrangements intended to give better rectification, unless the feed to the column is pre-heated by acting as cooling medium in the condensers.

5. The vapour velocity permissible is independent of the number of components in the mixture.

6. In general, if n products are to be taken off, sharp cuts can only be obtained by the use of n-1 columns. Thus for separating crude petroleum into gasoline, kerosene, gas oil and fuel oil in a continuous still, three columns must be used.*

* In marked contrast with the last condition, Reid[4] describes a plant in which one fractionating column deals with the vapour from five of six shell-stills operated continuously in series. The vapours from these five stills are carried through a common vapour line and enter the middle of the column. In effect, therefore, the five shell-stills constitute a single-flash system, since separation of the oil into the required cuts is effected by fractional condensation and not by fractional vaporisation.

The advance in petroleum fractionating column design appears the more striking when we consider that not many years ago the plant employed was crude by comparison with ordinary laboratory fractionating equipment, whereas nowadays the large-scale plant is precise by comparison with the same small-scale apparatus. Indeed, it is only very recently that, for example, Peters and Baker[5] have described a complicated laboratory distillation apparatus specially designed with the express object of bringing laboratory technique up to the standard of modern large-scale distillation operations.

The modern bubble tower consists essentially of a vertical cylindrical shell containing a number of horizontal plates. Each of these plates carries a certain number of "risers," each of which is covered by a "bubble cap." A certain depth of liquid is maintained on each plate and the rising vapour is constrained to pass through the risers where it is deflected downwards by the bubble cap, causing it to bubble up through the liquid on the plate. Provision is made to maintain a definite rate of down-flow of liquid from plate to plate. This is usually accomplished by means of a "partial condenser" or "analyser" on top of the tower, or it may be performed by pumping a certain amount of the cooled distillate into the top of the tower. If the crude oil is corrosive, the latter method is to be recommended. Corrosion is usually worst where products of b.p. 180° to 250°F. are undergoing condensation. Moreover, the pumping-in method eliminates the costly steel structures for supporting reflux condensers, and the difficulty and expense of repairs so far above ground. Using a pump, the partial condenser becomes merely a heat exchanger and may be set low. Provided the condenser is proportioned for emergency operation the tower will still function (at the cost of some extra fuel) should the exchanger fail. Either procedure has the same effect; "reflux" or "run-back" of liquid down the tower is provided, whereby a certain definite temperature-gradient is set up throughout the length of the tower, and scrubbing of the rising vapour is accomplished. Thus the vapour is subjected to a repeated and progressive partial condensation and redistillation until it reaches the top of the tower where it is free from heavy ends, and is passed either to the next tower or to the condenser. The heavier portion of vapour is condensed in the tower, stripped of all light fractions and drawn off at the bottom. Many variations upon this apparatus are possible. Thus

appropriate fractions may be withdrawn from various decks of the column, additional reflux may be introduced at various stages, and external stripping sections may be provided.* The whole apparatus, in fact, replaces the separate devices used on a multiplicity of shell-stills, with this advantage, that at every point accurate control of temperature and reflux is possible. In actual mechanical form, the components of a bubble tower may undergo many variations; a description of some of these, together with diagrams, is given by Reid.[6] The column designed by the Power Speciality Co. contains decks provided with long apertures, arranged parallel to a diameter, over which are long serrated covers maintaining a liquid seal, and provided also with two down-discharge pipes delivering condensate to opposite sides of the next lower deck. Corresponding decks in the equipment supplied by Badger, of Philadelphia, are fitted with a large number of apertures, each surrounded by a hemispherical serrated cap.

Control of the Tower

Regulation of the tower temperature is accomplished by controlling the quantity of reflux. For this purpose, there are two general classes of automatic instruments which behave satisfactorily in use: (1) pyrometer controls; (2) air-actuated controls.[7]

Undoubtedly the pyrometer is the more sensitive, and the sensitivity is not affected by the location of the instrument, which may be placed at any desired point. Moreover, the control may be accurately set to any predetermined temperature. There must, however, be a periodic make and break in a pyrometer temperature controller, and during the period that the thermocouple is disconnected from the motor-operated valve the reflux may become unbalanced, with the result that the tower temperature will fluctuate.

Air-actuated controls may be classified according to the filling of the capillary tubes; they may be mercury filled, vapour-tension, or gas-filled instruments. Each has its advantages and disadvantages, but as a class the control is more rapid than with a pyrometric instrument. Of the air-actuated controls, the mercury-filled instrument is the most sensitive and the most

* Since no plate is 100 per cent. efficient, the liquid on any tray is never entirely free from the light boiling fractions found on the trays above; removal of the last traces is effected in a special device external to the tower (stripping drum).

rugged; since, however, short tubing lengths are required, the instrument must necessarily be located near the point of control. Over the small range of settings to which it is limited the vapour-tension instrument is as sensitive as the mercury-filled instrument, and a greater length of tubing may be employed. This latter advantage is shared with the gas-filled instrument which lends itself to great flexibility from a practical standpoint. Moreover, it may be of the direct-set type, operating equally well over a wide range of temperature settings. It is not, however, so sensitive as the mercury-filled or vapour-tension instruments.

When the tower temperature is to be regulated by air-actuated controls while pumping reflux into the tower, it is well to combine a pressure regulator with the temperature regulator in order that there may be a fluid pressure ready to release the reflux liquid at the instant the control valve opens.

Although straight-line control is theoretically the most satisfactory, a variation of $\pm 2.5°$ is well within reason for all practical purposes, and may be accomplished with either pyrometer or air-actuated controls. The type of instrument to be installed can be determined only for the particular job under consideration; for example, if remote control is desired, pyrometer control is the most satisfactory, whereas if simplicity of equipment is the outstanding need, an air-actuated instrument should be installed.

Whether air-actuated or pyrometer controls are used, a by-pass line should be provided, through which a certain amount of reflux may be passed continuously. Thus the control valve will be required to pass only the variable amount of reflux to take care of temperature changes.

Advantages of the Pipe-Still Compared with the Shell-Still

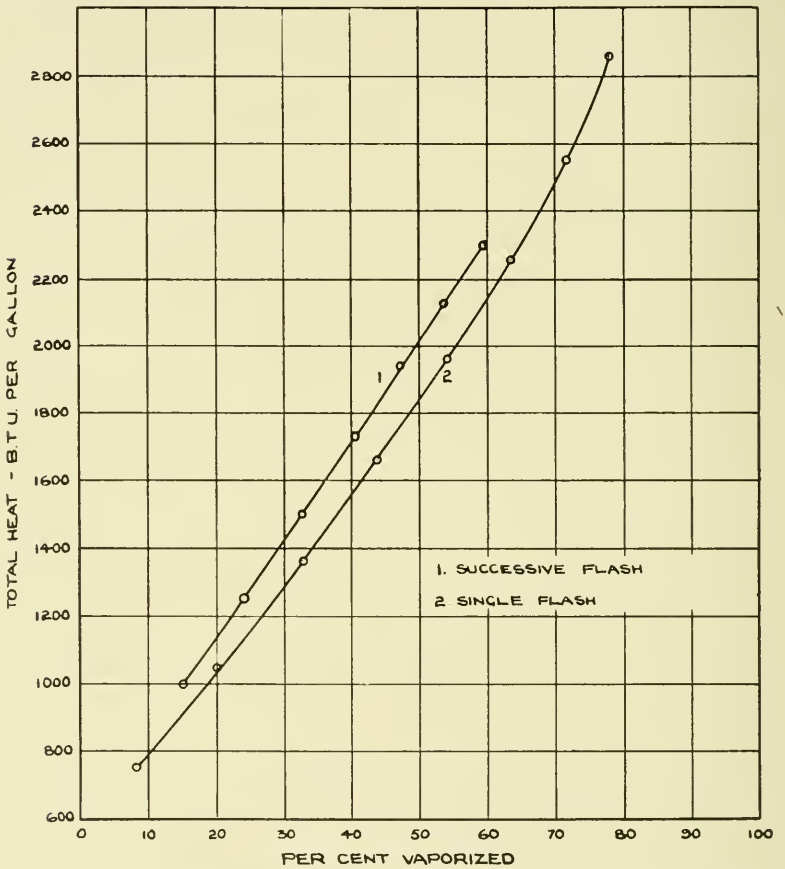
In a shell-still there is necessarily a large body of oil compared with the heating surface. Heat transference is largely dependent on natural convection currents and, since oil is a very poor heat conductor, there is great risk of local overheating and low thermal efficiency. The formation of hot spots on the still bottom is particularly undesirable when an oil (*e.g.*, lubricating stock) is being dealt with, the boiling range of which is close to the point at which incipient cracking becomes noticeable. The poor thermal efficiency of this type of still is illustrated by the fact that unless forced circulation is employed, not more than 3 to 4 B.Th.U. can

be absorbed per square foot per hour per 1° difference.[7] The pipe-still offers the obvious advantage of a much greater heating surface per unit volume of oil and a much more rapid flow of oil through the heated vessel. Moreover, the principle of the pipe-still renders possible much greater furnace efficiencies. Thus, with this type of still the heat transference is as much as 12 to 14 B.Th.U. per square foot per hour per 1° difference; hence much higher furnace temperatures and, therefore, more economical furnace design are possible. In pipe-still operation the crude oil loss (1 per cent. by weight or less) is much less than with shell-stills. A properly designed pipe-still may be operated with practically equal efficiency at, say, 60 per cent. of its rated capacity and with only very slightly decreased efficiency at, say, 125 per cent. of its rated capacity. Comparing the performance of shell-stills and pipe-stills, Leslie[8] quotes the following instructive data. The batch-stills and pipe-stills were operated at the same final temperature, 590°F., and in the former 54 per cent. was vaporised; in the latter, 77 per cent. The residue from the former contained 2.4 per cent. (on the crude oil) boiling below 450°F., whilst in the residue from the pipe-still there was less than 0.1 per cent. For equal work done, the final temperature at the pipe-still may be approximately 100°F. lower than the final temperature in the batch process. Perhaps the most striking feature about the combination of a pipe-still and a modern fractionating column is its flexibility. Should the supply of crude oil suddenly change in source or properties, or should the operator desire to produce different fractions, the hot-oil furnace outlet temperature may be altered almost immediately to meet the new conditions. Ample time is allowed in the convection section of a well-designed modern pipe-still furnace to obtain the maximum vaporisation at the minimum heating temperature, thus avoiding cracking with the formation of products difficult to refine. The fractionating equipment can be even more flexible than the furnace. Without altering the temperature of the hot oil from the furnace, both the amount and the quality of any or all of the products may be modified to meet any requirements. In fact, not only may crude oil be run to gasoline, kerosene, gas oil, wax distillate and an asphaltic residue, but the same unit may be used on a much higher throughput; in the latter operation, unlike convenient shell-still crude oil distillation and redistillation, sharply cut fractions may be obtained. The compactness, the

relatively small amount of steel used, ease of repair, and low capital cost of pipe-still units are also important factors when a comparison with shell-still installations is drawn. The risk of fire is also considerably diminished.

Methods of Operating Pipe-Stills

Leslie and Good[9] have carried out an extensive investigation into the single and successive flash methods of vaporising petroleum. For topping purposes the single-flash method is probably



HEAT REQUIRED TO REMOVE ANY PER CENT OF DISTILLATE FROM ONE GALLON OF CRUDE

Fig. 4.

the more economical, although where the crude must be run to a low residue the successive flash has advantages. Comparing

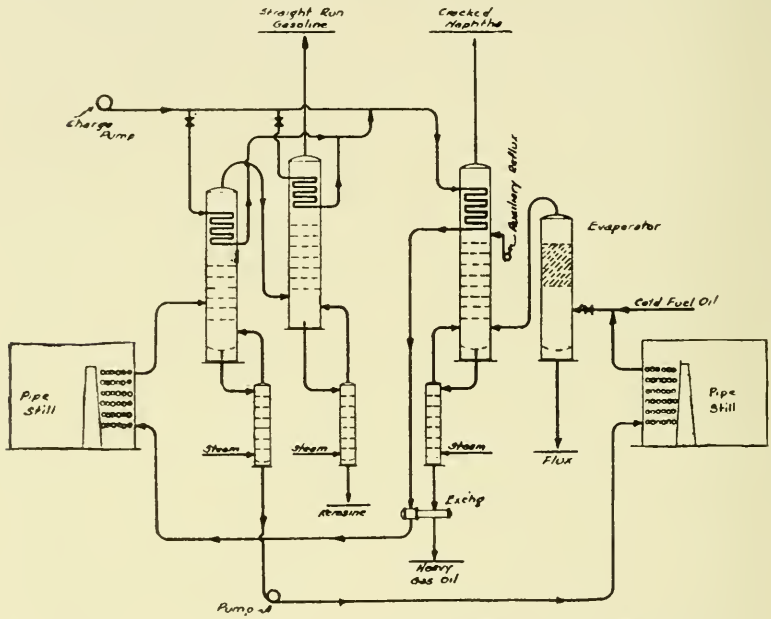
single with successive flash the proportion of single-flash distillate boiling below the flash temperature is 82.3 per cent., while for successive flashings the figure is 80.65 per cent. The curve (Fig. 4), presented by these authors, clearly indicates the superiority of single flashing. The total heat (in B.Th.U. per gallon) required to vaporise any given per cent. of distillate from one gallon of a paraffin base crude oil is consistently greater for successive flash distillations than for the single-flash method. Not only is less heat required, but the temperature necessary to remove a given fraction of the crude oil is less by the single-flash process. Where there may be, even with a pipe-still, some slight risk of cracking, the lower temperature required renders single-flashing preferable. Even successive flashings is, however, better than differential vaporisation or batch distillation in shell-still batteries. If shell-stills are employed, they would preferably be run as single continuous units—this being, indeed, quite a common practice.

F. C. Koch,[10] comparing various systems of pipe-still distillation, indicates that single-flashing offers the advantages that (1) the residue of, say, lubricating oil stock is obtained at a lower temperature than the final temperature which would be required to give the same residue in the second of two successive flashings; (2) there is no troublesome hot oil charging pump for the secondary still; (3) the pipe-still will not require cleaning so frequently as the secondary still of a double-flash system. Nevertheless, the double-flash system (Fig. 5) offers different advantages: (1) the first fraction, *e.g.*, straight-run gasoline and/or kerosene, is removed at a lower temperature than that required to flash the entire distillates in a single-flash still and therefore needs a minimum of treatment (2) the cracked gasoline resulting from the high temperature necessary to flash the gas oil is obtained separate from the straight-run gasoline obtained from the first still (3) although the second still will require cleaning more often than a corresponding single-flash still, the first still will require cleaning less often and need not be shut down during the idle period of the second still.

Recent papers in the technical press, particularly in America, describe many typical installations of pipe-still and column.

Thus, Smith discusses the plant of the Pure Oil Company, in which the fractionating columns are three in number. Each is $8\frac{1}{2}$ ft. × 70 ft., with two horizontal cylinders 16 ft. long placed

at right angles to the vertical axis of the tower, one at the top to house the heat exchanger and refluxing coils and one at the bottom to contain re-boiling coils. Fresh crude oil passes in series through the three reflux sections, thence to the residue heat exchanger and thence to the first heating section of the pipe still. It discharges into the lower (stripping) section of the first tower, gasoline being taken overhead whilst the residue returns



By courtesy of the "Oil and Gas Journal."

Fig. 5.

to the pipe-still and is vaporised. Unvaporised oil passes through the exchanger and away as fuel. The vapour enters the second tower. Gas oil and heavier oils flow from this tower through the reboiler coils of the third column and to storage. Overhead from the second tower may optionally be gas oil or kerosene.

Miller describes the three-tower pipe-still unit of the Marland Refining Company. In this system the crude oil, after passing through the heat exchanger, is flashed into the first tower and gasoline is taken overhead. The bottoms are pumped through the pipe-still and flashed into the second tower, from the base of which a stripped residuum is taken. An "omnibus" distillate of gasoline, kerosene and gas oil is taken from the top of this tower

to a point midway in the third tower, whence gasoline passes overhead, kerosene from a plate some distance down the tower and stripped gas oil from the base. The same refinery operates a single tower system from which gasoline, kerosene, gas oil and residuum are removed overhead and from plates at positions down the tower.

FRACTIONATION IN NATURAL GAS GASOLINE PLANTS

Natural gas is composed of methane, ethane, propane and butane, all of which are gaseous at the ordinary temperature and pressure, together with traces of higher paraffins such as pentane, hexane, heptane and octane. The compression gasoline isolated from this gas contains from a trace up to 5 per cent. of propane, 0.40 per cent. butane, 15.40 per cent. pentane, and all the hexane, heptane and octane originally present in the gas. The presence of propane is, however, undesirable, since very high vapour pressures cause loss of material by evaporation. The natural gasoline manufacturer of to-day is therefore confronted with the problem of preparing economically from the natural gas a gasoline which is "stable," that is to say which contains all the pentane and higher paraffins present in the gas, with as much butane as the market specification will allow, and with practically no propane. Originally, the natural gas gasoline (compression gasoline) was stabilised by weathering or simple distillation. This uneconomical process left much to be desired, but was continued as long as manufacturers were concerned only with reducing the vapour pressure and increasing the yield of non-stabilised gasoline from the gas. With increasing need for economy, improved methods of stabilisation were introduced, including vent tank separators, re-cycling, and finally fractionation. The credit for the earliest commercial attempt to separate propane from its heavier homologues is due to the National Carbon Company, their first plant being described by Rafferty in a paper read before the Association of Natural Gasoline Manufacturers at Tulsa in 1923. In effect, the crude gasoline was introduced under pressure into a rectifying column where it expanded. The most volatile material was introduced near the top, and as it expanded the temperature was lowered; there was thus a temperature gradient down the column and into a receiver connected with the bottom of the column. The receiver was provided with a steam

coil. The stabilised gasoline was withdrawn from this vessel and the propane left the column at the top. To illustrate the effect of propane on vapour pressure the following table (Burrell) may be quoted :—

TABLE II.

Propane content by weight.	Vapour pressure at 100°F. (lb. sq. in.).	I.B.P. °F.	F.B.P. °F.	Dist. loss
0	13	67	266	9
2	16.5	64	264	13.5
3	18.5	61	263	19
4	21	57	262	22
5	23.5	53	261	25.5

The Rafferty stabiliser was a definite improvement in the utilisation of natural gasoline, so much so, that at the present time stabilised gasoline has been put forward seriously as a complete motor fuel, *i.e.*, entirely independent of any blending whatsoever.

A typical modern stabilising plant consists essentially of a fractionating tower (a well-lagged, bubble cap column) with three points of entry at different levels. The latent heat of evaporation is used to maintain a very low temperature at the top, whilst steam heating gives a thermostatically controlled temperature of 60°F. at the bottom. The normal absorbtion gasoline that has been condensed under 30 lb. pressure is introduced near the bottom of the top section, containing fifteen bubble decks. The vapours from the stock tank, accumulator tanks and from the top of the stabiliser are collected and compressed to 50 lb. and, after cooling, the condensate is injected into the middle of the column. The "wildest" gasoline is injected on to the fourth plate from the top and the temperature due to its evaporation is about − 15°F. Pressure and temperature are automatically controlled.

The De Bray Stabiliser

This plant consists of a very efficient bubble plate fractionating tower, with a closed-steam heated boiler at the bottom and heat exchange equipment—all built to withstand 250 lb. per sq. in. pressure. A reflux condenser is incorporated in the top of the tower. The tower is 4 ft. diameter, 30 ft. high, and contains 26 bubble plates with inlet connections to each of the bottom ten plates. The high-pressure accumulator is a long cylinder containing the "wild" product; it has a float level control which operates the feed valve to the tower. The feed passes through two exchangers, where its temperature is raised to 150°F. It is injected on to the fourth plate from the bottom. The boiler has

a temperature controller operating the closed steam supply and is kept at 230°F. This hot stable product passes away through the exchangers and final coolers and is trapped to the make-tank, from which by level control it is fed to storage. The temperature at the top of the tower is 100°F., and the vapours pass into a reflux condenser having its cold water supply controlled by the temperature of the refluxed liquid, keeping the latter at 80°F. The vapour, leaving the reflux at 80°F., passes through a pressure controller which maintains a pressure of 185 lb. per sq. in. on the whole apparatus. This pressure is sometimes as high as 200 lb., being controlled by the quality of product desired.

Gregory[11] points out that high-pressure fractionation is usually more desirable because the reflux temperature may generally be controlled more easily and more economically than with low-pressure fractionation. Moreover, the use of high pressure (and therefore of a higher temperature) eliminates the possibility of the column freezing; this sometimes happens when a damp feed is charged to a low pressure column.

The following table illustrates the effect of method of preparation upon the composition of natural gas gasoline :—

TABLE III.

ANALYSES OF GASOLINES (RAFFERTY)

Constituent.	Absorbtion gasoline for blending. (1)	Weathered compression gasoline. (2)	Absorbtion gasoline. (3)	Absorbtion gasoline. (4)	Stabilised gasoline. (5)
Ethane ...	.0	.1	.1	.0	.0
Propane ...	5.0	3.9	3.2	1.6	0.0
Butane ...	55.2	21.8	19.2	14.8	40.2
Pentane and higher hydrocarbons ...	42.8	74.2	77.2	83.6	59.8
Vapour pressure, lb. per sq. in. at 100°F.	25	20	16	13	13

It will be seen from the above table that No. 5 is a well-stabilised gasoline that can be handled easily and shipped without blending. Furthermore, it is clear the presence of propane materially increases the vapour tension, whereas the presence of butane is not objectionable, normal and, in fact, desirable. At the present moment in many stabilising plants propane-free gasoline is being produced on a very large scale.

VACUUM DISTILLATION OF LUBRICATING OILS

Only quite recently has the possibility been considered of employing high vacua for the production of high-boiling,

lubricating oil fractions. The bulk of the lubricating oils made to-day from petroleum is still obtained by the use of shell-stills, which are operated under reduced pressure with the aid of a very considerable quantity of steam. This procedure suffers from two main disadvantages. The first is the very low thermal efficiency. The second is that oils particularly liable to thermal decomposition are held for prolonged periods in contact with hot metallic surfaces; in other words, every opportunity is given for deep-seated decomposition, with formation of coke and gas, and for the partial breaking down of the heavy lubricating oil to lighter oil of lower viscosity.

Steinschneider Process

Steinschneider[12] appears to have been the first actually to install plant for the manufacturing of mineral lubricating oil by distillation under reduced pressure. The principle of his process consists in carrying out the distillation in two entirely distinct stages. When the raw material has been heated to the distilling temperature, the unsaturated hydrocarbons, the permanent gases and the lightest products which result therefrom are removed in the first phase; in the second phase the distillation of the desired products, the more saturated hydrocarbons, takes place in one or in several entirely separate apparatuses, the various products obtained being cooled and condensed separately in an appropriate cooling device.

The raw material—crude oil, topped oil, residuum, etc.—circulates continuously between the distilling apparatus and a heating apparatus and is gradually heated to its end temperature each time it passes through the latter, and not once only. The lower the increase in temperature resulting from each individual passage of the liquid through the heating apparatus, the better can the separation of the decomposed products from the saturated hydrocarbons be effected, according to the difference in the boiling points, as the boiling point of the saturated constituents is higher than the boiling point of the unsaturated products which appear at the same distillation temperature.

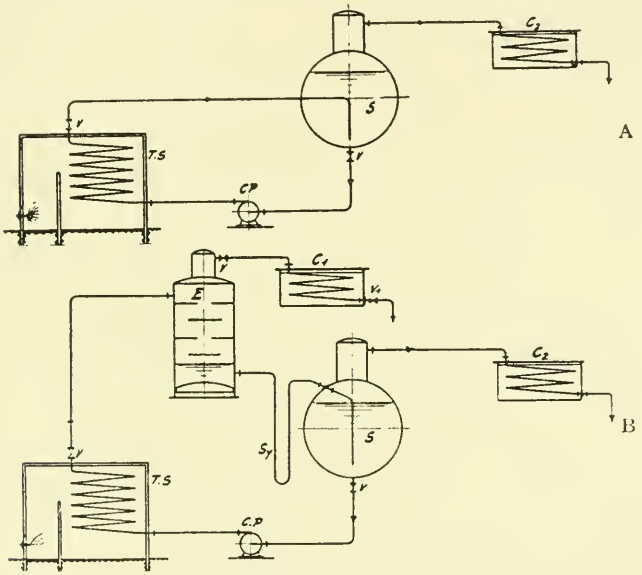
In the examples illustrated in the Figures 6 to 8 the process is carried out discontinuously.

Fig. 6 shows the fundamental principle of an ordinary distillation with a still "S" which is not direct fired and a pipe-still "TS"

which is heated by a burner. By means of the circulation pump "CP" the liquid material is circulated between the still and the heated coil until the raw material is distilled down to the concentration desired.

Fig. 7 shows the apparatus for the two-stage distillation.

The liquid material circulates between the still "S," the heated coil "TS" and the evaporator "E," so that before entering the still "S" the liquid material passes the evaporator "E." The pressure in the evaporator "E" is so high, that only the permanent



Figs. 6 and 7.

gases, the lightest fractions and the products of thermal decomposition escape owing to their boiling point. The liquid raw material, which is thus stripped of the decomposed products in evaporation chamber "E," then passes through the syphon "Sy" to the distilling chamber "S," which is not direct fired and in which the evaporation of the heavier fractions, *i.e.*, the desired products, is effected owing to the lower pressure. The pressure difference between the apparatus "E" and "S" is maintained by throttling the valve "V," and the flow of the liquid material from "E" to "S" is regulated automatically by syphon "Sy." The apparatus may be adapted to work under vacuum by means of a two-stage or three-stage air pump by connecting the evaporator

"E" with the air pump, which produces the higher absolute pressure and the still "S" with the air pump, which produces the lowest absolute pressure.

Fig. 8 is the scheme of a distilling plant similar to that of Fig. 7, but operating under vacuum. The arrangement is made so flexible that the plant can work either under an absolute pressure of 5 mm. without steam, or at a higher absolute pressure

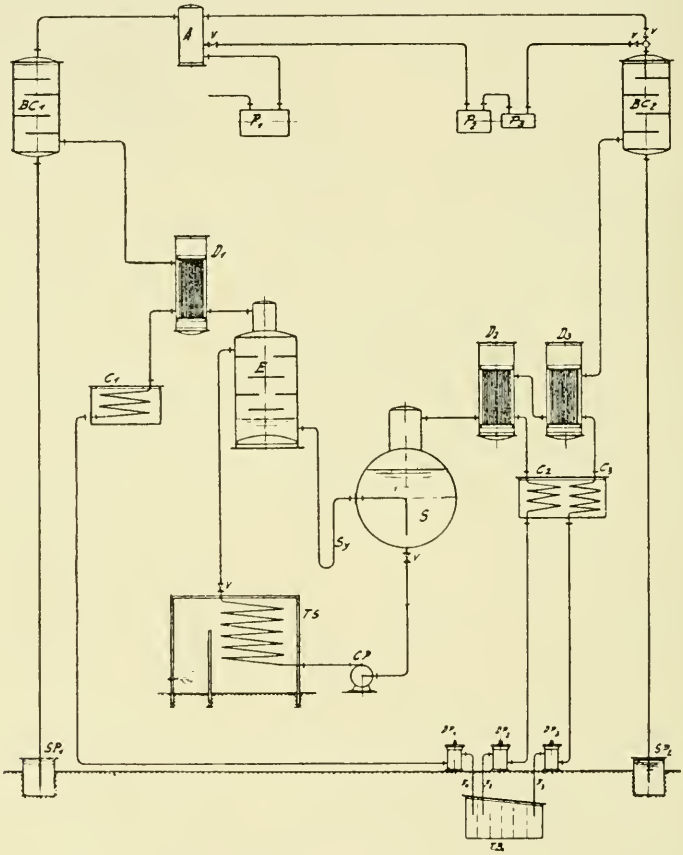


Fig. 8.

with steam, so that steam can be injected both into the evaporator and into the still. The plant is equipped with two barometric condensers, one for the evaporator "E" and another one for the still "S." If steam is used in "E" and "S" water is injected for cooling in both barometric condensers. In this case the two-stage

air pump "P2P3" is cut out, and the uncondensable gases are sucked out of the two barometric condensers only by air pump "P1." When steam is not used, the two-stage air pump "P2P3" sucks the uncondensable dry gases out of the barometric condenser "BC2" whilst the air pump "P2" draws off the uncondensable gases from the barometric condenser "BC1." When steam is injected only into the evaporator "E," cooling water is only injected into the barometric condenser "BC1." The exhaust of the air pump "P2" is connected with the collector "A," from which the air pump "P1" is sucking. By this means the two-stage air pump works like a three-stage pump. When distilling without steam the following absolute pressures are easily produced: in evaporator "E" an absolute pressure of 25 to 50 mm., in the still "S" an absolute pressure of 4 to 5 mm. But by distilling the same material with injection of steam, and with an absolute pressure of about 50 mm. a difference could not be detected in the quality of the distillates. This arrangement renders it possible to operate at any time with steam and a vacuum of about 30 mm., or without steam and a vacuum down to 4 mm. The air pump "P2P3" for distilling with a vacuum lower than 25 mm. can be installed at any time if practical tests show that better results can be obtained by the use of this high vacuum.

Schulze Process[13]

The advantages and markedly different results obtained by distilling lubricating oils at absolute pressure of 3 to 5 mm., as contrasted with former practice at 40 mm. or higher, appear to have been first shown, and the practicability of so operating industrially first demonstrated by Schulze.

The effect on the boiling point of lowering the absolute pressure is much more pronounced, for a given difference in pressure, at very low pressures than at moderate vacuum. A black oil distilled by Schultze illustrates this (Table 4).

TABLE IV.

Absolute pressure mm. H.	Per cent. over at 572°F. (300°C.).	Initial b.p. of fraction °F.
40	30	455°
25	50	437°
15	68	419°
5	94	364°

The rapid lowering of boiling points with decrease of absolute

pressure, particularly at low pressures (below 40 mm.) is shown by Fig. 9 (Steinschneider).

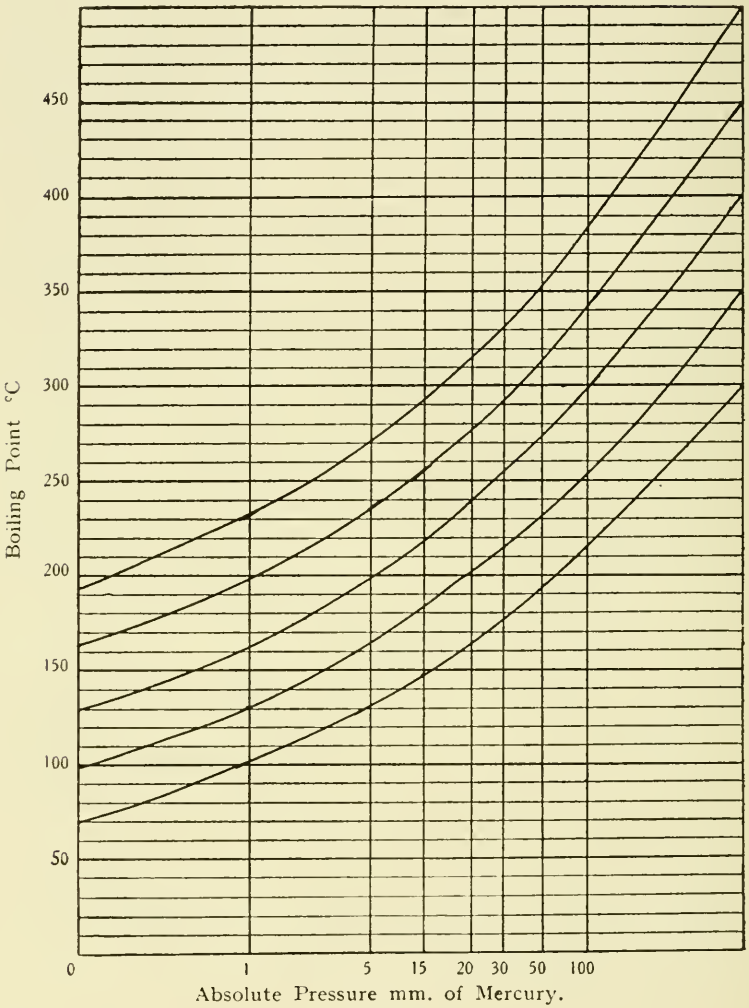


Fig. 9.

It is, of course, true that at absolute pressures as low as 3 mm. the oil vapours occupy a large volume, approximately 250 times the volume at atmospheric pressure, though this volume ratio is slightly reduced by the lower distillation temperatures resulting from the low pressure. In order to provide for this large vapour

volume and prevent the choking effect which would result from the usual still construction, Schultze provides as many as ten vapour outlets, 10 in. diameter each, on each 10 by 30 ft. vacuum still. With this multiplicity of vapour outlets the still shows practically the same absolute pressure, within 1 mm., as shown by the manometers on the receivers and on the lines adjacent to the vacuum pumps. These outlets dip slightly away from the still, considerable condensation being effected by air cooling before passing to the water-cooled condenser, which functions as much as a cooler as a condenser. Somewhat less than 1 per cent. of light, volatile, malodorous oil is taken off in a separate overhead line, leading to a separate condenser; this overhead vapour and gas line is directly connected to the vacuum pump. The bulk of the distillates flow by gravity to a series of receivers which are evacuated at the beginning of the run, the evacuation proceeding through the condensers and light overhead line to the vacuum pump. The stills and all the lines are welded throughout.

The vacuum pumps employed have been considerably improved to meet the requirements of this process. The power consumption is very small, two vacuum pumps being mounted on one base and driven by one 40-horse-power motor. Worthington "feather" valves are a noteworthy feature of these pumps, as is the general pump design, which practically eliminates dead air space.

High vacuum distillation is probably most advantageous in the case of wax-free oils because the absence of paraffin wax makes the production of finished lubricating oils in this way an exceedingly direct and simple process. Gasoline and kerosene, if present, should be removed in a preliminary topping distillation, and, although some gas oil may be taken over in this way, care should be taken not to crack the oil. Very heavy crude oils are first dehydrated and charged into a vacuum still, the gas oil distilled under a moderate vacuum, and the vacuum then raised to the usual operating pressure.

In this method of batch operation the still temperatures may reach 570° to 625°F., depending upon the properties of the oil and its resistance to cracking. The lubricating oil distillate thus obtained is emulsified with just sufficient concentrated caustic soda to combine with the naphthenic acids, and without separating the soaps the oil is redistilled at 3 to 5 mm., cutting the fractions according to the viscosity desired. These distillates are colour-stable and substantially odourless and tasteless without acid or

any other treatment. In order to remove moisture and brighten the distillates, the receivers are provided with closed steam pipes by which means the oil is heated to about 200° to 225°C., and blown with air at this temperature until bright. No other refining treatment is necessary if the charging stock has not been previously damaged by cracking and the distillation has been properly carried out.

One of the characteristics of lubricating distillates produced by high-vacuum distillation is that the cuts can be made quite narrow corresponding with a narrow range of boiling point and viscosity. In the usual practice gas oil is produced by cracking of the more valuable lubricating oils throughout the distillation period. It is the presence of these light decomposition products in very substantial proportions which gives such distillates their pronounced odour and taste, makes them become discoloured on exposure to air, and necessitates the use of sulphuric acid, alkali, and usually fuller's earth to render them marketable. The troubles incident to the refining of lubricating oils with acid, alkali, etc., are too well known to warrant comment. That the colour stability and other properties of the distillates produced by the Schulze process are such that no acid is required to refine them has already been noted. This colour stability is also indicated by the fact that the final distillates can be heated to 250°F. and blown with air until bright without darkening in colour. The values reported for Conradson carbon and demulsification are also noteworthy.

Use of Mercury Vapour for Heating Lubricating Oil Vacuum Stills

An account is given by Klemgard[15] of a process (*cf.* Fig. 10) for producing lubricating oils by distillation, under a vacuum of 10 mm. or less, in a battery of stills heated by means of mercury vapour. The entire mercury vapour system is maintained under a pressure of 8 to 10 lb. per sq. in. in excess of atmospheric. The boiler is so designed that liquid mercury enters the open tops of a series of vertical 4 in. steel tubes closed at the lower ends. The mercury vapour formed in these heated tubes passes into the upper part of the boiler and thence to a series of heat exchangers or evaporators, each of which forms the base of a fractionating column. Partial condensation of mercury occurs in each heat exchanger, the condensed mercury being drawn off and returned

through a common line to the boiler. Topped crude oil (Smackover crude oil is specially mentioned) is heated with 1 to 2 per cent. of 50 per cent. aqueous sodium hydroxide in a shell-still and is then heated from 350° to 450°F. in heat exchangers. It now enters the first evaporator, *i.e.*, that most remote from the mercury boiler, where it undergoes partial vaporisation, the vapour rising into and being fractionated in the superimposed column. The residue passes to the next evaporator and so on until the tenth

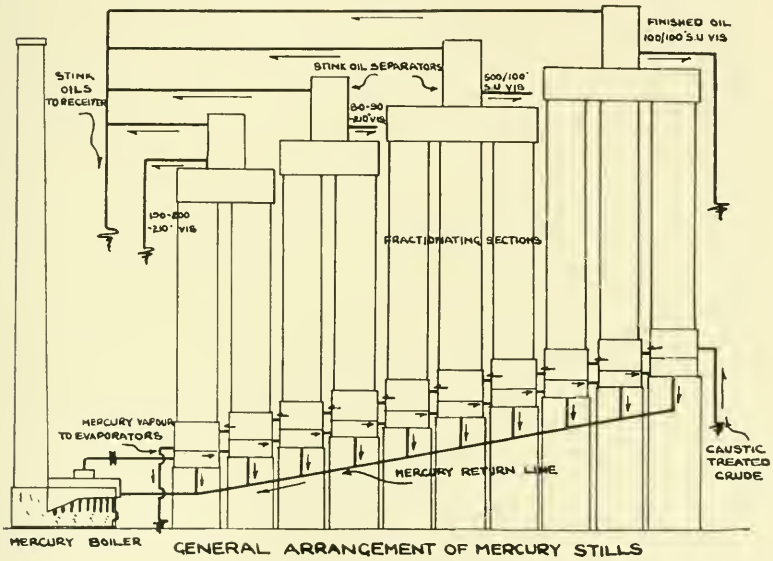


Fig. 10.

and last is reached. Two or more adjacent columns are sometimes joined at the top by horizontal headers, on which additional separators are placed. Lubricating oil fractions, which do not require further refining, are drawn from the base of these additional separators, from the top of which the vapour of unsaturated, volatile oils of foul odour ("stink oils") forming about 9 per cent. of the topped crude oil, are drawn off and carried to heat exchangers and condensers. The whole of the fractionating system is maintained at a pressure of, usually, 6 to 7 mm. It is claimed for this process that local overheating is avoided and close regulation of heating achieved, and that high viscosity oils of very pale colour are produced.

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ZUSAMMENFASSUNG

Die moderne Destillierblase bietet viele Vorteile. Unter diesen ist wohl der wichtigste die erhöhte Wärmeübergangsgeschwindigkeit, besonders wenn man es mit schwersiedenden Produkten zu tun hat, die zum Cracken neigen, sobald sie etwa auf ihre Siedetemperatur erwärmt werden. Weitere Vorteile sind: Gedrängte Bauart, geringerer Stahlaufwand in der Konstruktion, leichteres Reparieren und geringere Kosten. Die Feuersgefahr wird ebenfalls beträchtlich verringert. Die moderne Destillierblase ist in Verbindung mit einer sachgemäss konstruierten Fraktionierungssäule äusserst anpassungsfähig. Ein für einen bestimmten Zweck gebautes Aggregat kann durch blosses Ändern der Betriebsverhältnisse leicht darauf umgestellt werden, ein verschiedenes Erzeugnis zu liefern oder ein anderes Rohmaterial zu verarbeiten.

Von Propan befreites Gasolin aus Naturgas kann ohne erhebliche Verluste behandelt werden. Die Destillation und Fraktionierung zwecks Entfernung des Propans werden bei erhöhtem Drucke vorgenommen, wodurch die Nachteile des Arbeitens bei niedrigen Temperaturen wie z.B. die Gefahr des Einfrierens vermieden werden.

Neue Fortschritte im Bau von Anlagen hat die Anwendung von verhältnismässig hohen Vakua (3–5 mm) beim Destillieren von Schmieröl möglich gemacht. Auf diese Weise lassen sich Schmieröle ohne ungebührliches Cracken bereiten, die, um marktfähig zu sein, nur wenig weitere Behandlung erfordern.

Eine interessante Methode der Destillation von Schmieröl bei vermindertem Druck wurde letzthin beschrieben, wobei die Wärme unter leicht erhöhtem Druck durch Quecksilberdämpfe zugeführt wird.

CHEMICAL REACTIONS INVOLVED IN THE REFINING OF PETROLEUM

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS

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Paper No. F5

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CHEMICAL REACTIONS INVOLVED IN THE REFINING OF LIGHT DISTILLATES

At the present time petroleum is never used in the crude state in which it is obtained from the well. The wide range of volatility of its constituents renders the preparation of an almost infinite number of fractions possible by distillation. The cuts usually made in practice fall, however, into four main classes: gasolene, kerosene, heavy oils and pitch (residue). Although petroleums consist mainly of hydrocarbons, smaller quantities of other organic compounds containing sulphur, oxygen, or nitrogen are usually present as well as traces of inorganic substances*; the latter are generally found in the ash or flue dust (*e.g.*, vanadium) when the petroleum is burnt. On distillation the inorganic impurities remain in the residue, but the original organic sulphur-, oxygen- and nitrogen-containing constituents of the petroleum and the products of their thermal decomposition, being at least partly volatile, are distributed throughout the range of fractions. As these bodies are generally considered to impair the quality of the products it is usual to remove them or convert them into less objectionable substances.

* It is very possible that certain inorganic constituents (*e.g.*, nickel and copper) are present in the form of oil-soluble naphthenates.

Modern petroleum products—distillates in particular—are in fact very highly refined. A fastidious and technically uneducated public asks for materials which are satisfactory in an æsthetic as well as a technical sense. This demand was initiated at least partly by the opening up of fields, chiefly in Pennsylvania, yielding petroleum which consisted almost entirely of hydrocarbons and which, therefore, gave distillates of unexceptionable odour and colour and, furthermore, of low sulphur content. The consumer was very readily pursuaded that these qualities were necessary, and that such distillates were better than others of higher sulphur content and less agreeable odour. When the oil industry expanded into Ohio and Canada, oils of comparatively high sulphur content were encountered;[1] to satisfy public demand and to meet competition new and costly methods* of dealing with sulphur-containing oils had to be adopted.

A consideration of the qualities required of various products and the effect of possible impurities shows that some distinction should be made. Thus a motor spirit must be non-corrosive and, especially for use in a closed car, of unobjectionable odour. It must not deposit gum in the carburettor or on the inlet valves, but colour, when it does not arise from gum or gum-forming constituents, is of no real importance; this distinction is particularly significant when considering cracked gasolene made by cracking heavier oils (*vida infra*). The presence of small quantities of sulphur compounds which are neither corrosive nor unpleasant in odour does not matter. An excessive content of sulphur would be harmful because, although the products of combustion (sulphur dioxide and sulphur trioxide) do not have any injurious effect in the cylinder head, moisture is always present in the crank-case, and the resulting acid solution formed from water and the sulphur oxides would be corrosive, particularly on standing.[2] Tests on various sulphur derivatives have shown that they do not possess any pro-knock action. A motor spirit must be stable, *i.e.*, it must retain its qualities on keeping. Like a motor spirit, kerosene for burning in lamps must be of pleasant odour, hence certain types of sulphur compound must be absent. The permissible content of sulphur is also restricted because sulphur causes bad burning, charring of the wick, and filming of the lamp glass. As with a motor spirit, the colour of a kerosene is of no importance unless it is due to the presence of

* The first of these was the Frasch process.

material which would char the wick. It is therefore evident that some discrimination may be made in deciding which qualities should determine the necessary degree of refining of petroleum products, and also that refining has been carried unnecessarily far in the past.[3]

It is obvious that excessive refining is wasteful. Sometimes it may be doubly so. For example, if a cracked gasolene is refined by means of sulphuric acid to reduce the sulphur content, valuable anti-pinking constituents are removed.[4] The lower the required sulphur content of the refined oil, the more acid is needed and the greater is the loss of valuable material. But the waste is not confined to the refining process. The finished cracked gasolene will have to be blended with benzene to bring the anti-knock power up to the same figure which it would have had after less drastic refining.* Alternatively, the over-refined oil may be used as such, but its use will be restricted to engines of lower compression and therefore lower efficiency, in which the petrol consumption will be greater. It is not surprising that there is to-day a tendency to cut down refining to the necessary minimum.† This is only made possible by research into the mechanism of refining processes and into the chemistry both of the oil itself and of the impurities which must be removed.

LIQUID REFINING AGENTS

Soda-washing

Of the substances the presence of which is undesirable in petroleum distillates, sulphur and its derivatives are the most widespread and the most costly to remove. Sulphur occurs in the distillates in many different forms, which are of different types and which react towards refining agents in different ways.

A small proportion of the sulphur occurs in the free or elementary state;‡ a comparatively large proportion is present as hydrogen sulphide, while the remainder is in the form of organic derivatives of sulphur. The last are divisible into two classes: (1) acidic, a

* Egloff and Lowry suggest that since engine corrosion by sulphur acids is due to condensation of water in the crank-case and is entirely a cold-weather phenomenon, the refining of motor spirits should be altered in accordance with climatic change. Gasolene required for warm-weather use—the greater part of the year's consumption—need not be desulphurised, since corrosion does not occur during the summer regardless of the sulphur content of the fuel.

† Thus it has been estimated[4] that the loss in anti-knock value, when the cracked distillate from Californian crude oil, having a sulphur content of 0·9 per cent., is acid treated to reduce the sulphur content to 0·1 per cent., is approximately 17 per cent. of the anti-knock value obtained using the minimum treatment to render the spirit saleable. There is an additional 10 per cent. loss of material when sufficient acid is used (30 lb./bbl.) to bring the sulphur content down to 0·1 per cent.

‡ Generally resulting from aerial oxidation (*vide infra*).

property shared with hydrogen sulphide and due to the presence of the ·SH group, and (2) neutral. The first includes mercaptans which, together with hydrogen sulphide, are mainly responsible for the unpleasant odour of the unrefined distillates and for the positive reaction of the well-known "doctor" test (see below). The second class includes the organic sulphides and disulphides.

Free sulphur cannot on any account be tolerated in a light distillate. In gasolene it is highly corrosive to metals, it causes kerosene to burn badly and to film the lamp glass, and in white spirit, which is largely used for dry cleaning, it gives hydrogen sulphide on redistillation, thus fouling the recovered solvent. The chief source of free sulphur in light distillates is hydrogen sulphide, which undergoes oxidation with great readiness by the action either of atmospheric oxygen or of reagents commonly used in refining (such as sulphuric acid or hypochlorite). It is therefore evident that the complete removal of hydrogen sulphide must be effected before the light distillate is further treated.*

Hydrogen sulphide can be removed by water-washing. This is, however, too lengthy a process and requires too much water for general practice; it is therefore usual to employ sodium hydroxide solution instead. Hydrogen sulphide is converted into sodium sulphide or sodium hydrogen sulphide (*vide infra*), either of which remains in the wash-liquors. Qualitatively the acidic organic sulphur derivatives, the mercaptans (RSH, where R is a hydrocarbon radicle), behave like hydrogen sulphide. But, whereas the latter is dibasic and is a comparatively strong acid, the mercaptans are monobasic and are only weakly acidic.[5] The sodium mercaptides are in fact readily hydrolysed by water; in other words, the reaction by which they are formed is reversible:

$$RSH + NaOH \rightleftharpoons RSNa + H_2O.$$

Consequently the removal of a mercaptan from petroleum by agitation with aqueous alkali is never complete; a balance is eventually attained between the concentration of mercaptan (as free mercaptan) in the oil and the concentration of mercaptan (present largely as alkali mercaptide) in the aqueous solution. Moreover, the acidity of the mercaptans (the ease of replacement of the acidic hydrogen atom by a metal) rapidly falls off as the molecular weight of the hydrocarbon radicle, R, is increased. This is well brought out in the following table.

* If plumbite is to be used, a previous treatment with soda effects an economy in lead.

Compound.		Boiling point.	Percentage removed from petroleum solution by same quantity of soda solution under identical conditions.
Hydrogen sulphide	H_2S	Gas	100
Ethyl mercaptan	$C_2H_5.SH$ ...	39°C	97·1
n-Propyl ,,	$C_3H_7.SH$ ...	68	88·8
*iso*Propyl ,,	$C_3H_7.SH$ ...	59	87·2
n-Butyl ,,	$C_4H_9.SH$ ...	98	63·2
*iso*Butyl ,,	$C_4H_9.SH$	88	62·8
*iso*Amyl ,,	$C_5H_{11}.SH$ ...	118	33·0

When discussing the difficulty of effecting mercaptan removal from even a light distillate by soda washing this table is highly instructive. Consider the highest mercaptan examined, *iso*amyl mercaptan. It has a boiling point of 118°C. and under the conditions of the experiment (which are comparable with the usual works practice when batch-washing) only 33 per cent. was removed. It is unusual for more than 50 per cent., say, of a distillate which is to be soda-washed to be volatile at 118°, so that there is 50 per cent. of higher boiling material. If the mercaptans were evenly distributed there would likewise be 50 per cent. of mercaptans even less readily removable by soda than *iso*amyl mercaptan. The actual figure is probably even higher as shown by the figures for distribution of sulphur. It follows that the complete removal of acidic bodies by soda washing alone is almost impossible; by the batch process, the attainment of equilibrium between mercaptan in the oil and mercaptan in the soda makes complete removal absolutely impossible. Nevertheless, even by the batch process hydrogen sulphide can be entirely eliminated by soda-washing; stress must be laid on this in view of the necessity for removing hydrogen sulphide prior to any subsequent process involving oxidation.

With efficient mixing the balance represented by the reversible equation

$$RSH + NaOH \rightleftharpoons RSNa + H_2O$$

is rapidly attained. A multiplicity of washes is, therefore, of advantage; the even greater benefit of the continuous, counter-current method, in soda-washing, is at once evident.

The effect of concentration of soda upon mercaptan removal is considerable and rather surprising. Mayer and Smith of the Anglo-Persian Oil Company (private communication), have shown recently that a given weight of sodium hydroxide will remove more of a given mercaptan from a standard solution in petroleum the greater the

dilution at which it is used. The explanation given of this relationship, which is true only when the weight of alkali is great compared with the total mercaptan present, is as follows. When a mercaptan is added to aqueous sodium hydroxide, or when a sodium mercaptide is dissolved in water, the following equilibrium is set up:

$$RSH + NaOH \rightleftharpoons RSNa + H_2O.$$

If water is added to this system the equilibrium is displaced to the left, that is, more sodium mercaptide is hydrolysed with production of free mercaptan. But if, for example, the system consisting of water, sodium hydroxide, sodium mercaptide and mercaptan is diluted to twice its volume, the quantity of free mercaptan in the aqueous solution will not be doubled, but will only be increased by some lesser factor. Thus the concentration of free mercaptan in the diluted aqueous solution will be less. But if the aqueous solution containing (amongst other substances) mercaptan is in contact with a petroleum solution also containing mercaptan, there is a constant partition coefficient, *i.e.*,

$$\frac{\text{Conc. RSH oil}}{\text{Conc. RSH water}} = K,$$

and this partition coefficient is dependent purely on the solubility of the mercaptan in the oil and in the water, and is entirely independent of the presence of other materials. If, therefore, the aqueous solution is diluted and the concentration of free mercaptan therein decreased, more mercaptan must pass from the oil to the water to maintain the constant partition. That is to say, the efficiency of a given weight of sodium hydroxide for removing a mercaptan from petroleum solution is greater the less the concentration at which it is employed.

Besides its acidic character there is another property of the .SH group which has an important bearing on soda-washing. Compounds containing this group readily undergo oxidation ; thus hydrogen sulphide is oxidised to elementary sulphur, and mercaptans to organic disulphides. Oxidation may be brought about by atmospheric oxygen or by free sulphur; in the oxidation of mercaptans the latter agent is particularly effective in the presence of aqueous soda. Free sulphur can only be removed from the oil with difficulty. Since, therefore, it is produced from hydrogen sulphide with great readiness by aerial oxidation, it is of the highest importance that unrefined light distillates should be soda-washed as soon after production as possible and that until this is done contact with

the air should be avoided. Distillates should, therefore, be washed at the worm end.

The aerial oxidation of mercaptans is probably slight, but oxidation undoubtedly occurs in the soda solution during soda-washing through the agency of alkali polysulphides. These are formed from elementary sulphur in the unrefined oil and sodium sulphide (derived from hydrogen sulphide). The products of oxidation, disulphides, are neutral substances which, being insoluble in soda, return to the petroleum during the soda treatment. If desulphurisation is aimed at, this return of sulphur to the oil as disulphide entails a heavier subsequent treatment. The formation of disulphides depends, as indicated, on the elementary sulphur in the unrefined distillate. We have here, then, an additional reason for avoiding the production of free sulphur, by atmospheric oxidation of hydrogen sulphide, as far as possible.

A comparison of the boiling points of the mercaptans and of the disulphides derived from them shows how distillation following soda-washing reduces the sulphur content of the gasolene.

Mercaptan.	Boiling point. °C.	Boiling point of Disulphide. °C.
Ethyl	39	152
*iso*Propyl	59	175
*iso*Butyl	88	220

Owing to their comparatively high boiling points the disulphides are left in the residue as they are outside the boiling range of the distillate, although the parent mercaptans fall well within that range.

The "spent soda" leaving the washers is yellow in colour and has an odour of mercaptans. Owing to the presence of alkali polysulphides it is difficult to reclaim and is therefore allowed to pass into the effluent.

It is obvious that a great economy would be effected by using lime instead of sodium hydroxide. There is, apparently, no reason why this should not be done; at least one large refinery is now using lime in place of soda for the washing of light distillates throughout the refining process.

Sodium Sulphide Washing

Mention has already been made of the fact that sodium sulphide solution reacts with free sulphur in petroleum solution to give sodium polysulphides. Use has actually been made of this reaction to remove elementary sulphur from petroleum distillates.

Further action of hydrogen sulphide on sodium sulphide solution results in the formation of sodium hydrogen sulphide:

$$Na_2S + H_2S = 2\,NaSH$$

Air-blowing reverses the above reaction (owing to the volatility of hydrogen sulphide) with regeneration of a solution of sodium monosulphide, which may be again for reacting with hydrogen sulphide. Sodium sulphide solution (spent soda) has been employed in this way to remove hydrogen sulphide from natural gas (Mayer and Smith).

Sodium Carbonate

Sodium carbonate solution can be employed to wash oils when acid substances only have to be neutralised. Thus it can be used after the acid-washing of straight-run distillates to remove traces of acid and after sulphur dioxide treatment to remove the last traces of sulphur dioxide left in the oil. It is particularly useful for cracked distillates, as it does not cause much polymerisation.

The Plumbite Process

In this process, which is used for sweetening "sour" oils* a solution of sodium plumbite ("doctor" solution) is employed: this is prepared by dissolving litharge in aqueous sodium hydroxide. The term "sour" implies the possession of a disagreeable odour or of reactivity to "doctor" solution; the "doctor" test is more sensitive than the simpler test of odour.

The commonest cause of sourness is hydrogen sulphide, which reacts with sodium plumbite to give lead sulphide. The use of plumbite solution for removing hydrogen sulphide is, however, unnecessary and wasteful, since a complete removal may be effected by soda-washing (*q.v.*). For this reason, a distillate which contains hydrogen sulphide should always be treated with soda previous to plumbite treatment.

Sourness is also caused by mercaptans, the reaction between a mercaptan and sodium plumbite† leading to the formation of lead mercaptide.

$$2\,RSH + Na_2PbO_2 = (RS)_2\,Pb + 2\,NaOH.$$

The lead mercaptide may be yellow to red in colour according to the hydrocarbon radicle R; the lower, lighter coloured lead mercaptides

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* Plumbite treatment also removes alkyl sulphates as lead sulphate in the sweetening of acid-treated cracked distillates.[6]

† The solubility of mercaptans in caustic soda solution is of considerable importance in bringing the plumbite and mercaptans into contact.

are precipitated in the aqueous layer (the precipitate is known technically as a "rag"), while the higher members of the series are soluble in the oil, to which a red colour is imparted (the colour reaction of "doctor" solution with a mercaptan is, ofcourse, masked if hydrogen sulphide is present in any quantity). Thus the action of sodium plumbite alone results in a partial desulphurisation, lower mercaptans being removed as a precipitate whilst the higher mercaptans remain in the oil as oil-soluble lead mercaptides. The latter must, of course, be removed. This is accomplished by the addition of free sulphur when the following reaction occurs:

$$\begin{matrix} RS \\ RS \end{matrix}\!\!>\!Pb + S = PbS + \begin{matrix} RS \\ | \\ RS \end{matrix}$$

Black lead sulphide is precipitated and a disulphide is formed which remains in or passes back into the oil.[7] By this process sweetening is therefore completed, since disulphides are not reactive to plumbite solution; practically no desulphurisation occurs, however. What little desulphurisation takes place is due to adsorption of sulphur compounds (probably disulphides) on the precipitated lead sulphide. Free sulphur already present in the oil being treated will obviously enter into the above reaction with lead mercaptide.* The evils attendant upon elementary sulphur in refined oils make it obvious that great care must be exercised in adding free sulphur to complete the doctor reaction; the addition is usually made by means of a standard solution of sulphur in a portion of the oil to be treated.

Since sweetening is accomplished but not desulphurisation, if a product of low sulphur content is required the plumbite process must be followed by some other treatment (*e.g.*, acid washing). The recovery of lead from the sludge from plumbite refining has been accomplished by treating with spent acid (acid tar) from sulphuric acid refining, removing the aqueous sludge containing lead sulphate from the separated oil, and treating the lead sulphate with caustic soda whereby sodium sulphate and sodium plumbite are produced. Instead of treating with acid sludge, conversion of the lead sulphide into lead sulphate by air blowing at an elevated temperature has been largely employed.

Lead Sulphide Refining

An interesting development of the plumbite process has been

* Some distillates contain sufficient free sulphur. The addition of low boiling mercaptans together with "doctor" solution has been suggested as a means of removing free sulphur.

recently described.[8] A suspension of lead sulphide in aqueous caustic soda is used. The strength of the caustic soda solution may be from 10°–25°Bé, and is preferably about 20°Bé. The oil to be treated and the suspension of lead sulphide in caustic soda are mixed and air-blown. Mercaptans become adsorbed on the lead sulphide and undergo aerial oxidation to disulphides. The action is thus one of sweetening, no material desulphurisation being effected. The action of lead sulphide is mostly catalytic, although a small amount is converted to plumbite by the air introduced. The catalytic action is destroyed by the presence of small amounts of sodium sulphide. Sulphur assists in the sweetening but is not required.

Hypochlorite Process

The hypochlorite process is used principally for the desulphurisation or "sweetening" of light distillates, although it has been used for refining wax.

The process consists in washing the distillate with an aqueous alkali or alkaline earth hypochlorite solution under controlled conditions, this treatment being followed by a small soda wash to remove traces of hypochlorous acid, etc., dissolved in the oil. It is essential that the hypochlorite solution should contain sufficient free alkali to stabilise it, but insufficient to retard appreciably the interaction of the hypochlorite and the objectionable sulphur compounds of the oil. The reason for this was obscure when the hypochlorite process was evolved; much work on this subject has since been carried out with illuminating results (*v.i.*).[9]

Calcium and sodium hypochlorites are readily prepared by passing chlorine into well agitated milk of lime or caustic soda solution. At first it would appear difficult to regulate the alkali content as the later stage of the absorption proceeds, but the men engaged in this operation become exceedingly proficient; a pink colour, due to the oxidation of manganese salts to permanganates, generally develops when the preparation of the calcium salt is nearing completion. The freshly prepared solutions are roughly 2N and are diluted to a working strength of 0.2–0.3N; the calcium salt is allowed to settle before dilution. The free alkali content of the diluted "reactive" reagent is equal or equivalent to 0.5–1.0 gm. caustic soda per litre. Calcium hypochlorite can also be prepared from bleaching powder.

An investigation of the products formed by the interaction of

hypochlorites and sulphur compounds showed that the following substances were produced:

Sulphur compound.	Reaction Products. Sol. in oil.	Sol. in water.	Insoluble.
Hydrogen sulphide	(Sulphur)	Sulphuric acid	Sulphur
Ethyl Mercaptan	Ethyl disulphide	,, (trace)	—
		Ethane sulphonic acid	
*iso*Propyl mercaptan	*iso*Propyl disulphide	Sulphuric acid (trace) *iso*Propane disulphide sulphonic acid	—
*iso*Butyl mercaptan	*iso*Butyl disulphide	Sulphuric acid (trace) *iso*Butane sulphonic acid	—
Ethyl sulphide	—	Ethyl sulphone	—
n-Propyl sulphide	(*n*-Propyl sulphone)	*n*-Propyl sulphone	
*iso*Butyl sulphide	*iso*Butyl sulphone		
*iso*Amyl sulphide	*iso*Amyl sulphone	(*iso*Amyl sulphone)	—
*Pentamethylene sulphide	sulphone		
Diethyl disulphide		Ethanesulphonic acid Sulphuric acid	—
*iso*Amyl sulphoxide	*iso*Amyl sulphone	(*iso*Amyl sulphone)	—
Diethyl sulphone	no action		
Thiophene	no action		

The substances in brackets are fairly soluble in the layer under which they appear.

The results may be summarised as follows:

(1) Whereas hydrogen sulphide, mercaptans and disulphides all react to give at least some acid products, no acid products are formed from sulphides or sulphoxides.

(2) Thiophene and sulphones do not react under the conditions employed.

(3) Increase in molecular weight of the sulphur compound (*a*) decreases the rate of oxidation—di*iso*amyl disulphide hardly reacts at all—and (*b*) decreases the solubility of the neutral oxidation products which become increasingly soluble in the oil layer.

(4) Increase in the free alkali content of the hypochlorite decreases the rate of reaction considerably, and conversely.

(5) Dilution of the hypochlorite increases the rate of reaction.

The first point is of great importance, because the acid products neutralise the free alkali of the reagent as they are formed and thus progressively render the hypochlorite more reactive. Consequently, if insufficient alkali is originally present the aqueous solution may actually become acid, when there will be a tendency for chlorination to occur. As it was confirmed that the addition of free alkali stabilises the hypochlorite, the explanation of the narrow limits

* The pentamethylene sulphide was isolated from acid tar from Persian kerosene.

for alkali content necessary in large scale operations becomes clear. The retarding influence of free alkali, and the accelerating effect of dilution, are convincingly explained, on the assumption that the active oxidising agent is not sodium hypochlorite, but free hypochlorous acid produced by reversible hydrolysis:

$$NaOCl + H_2O \underset{NaHO}{\overset{H_2O}{\rightleftharpoons}} NaOH + HOCl$$

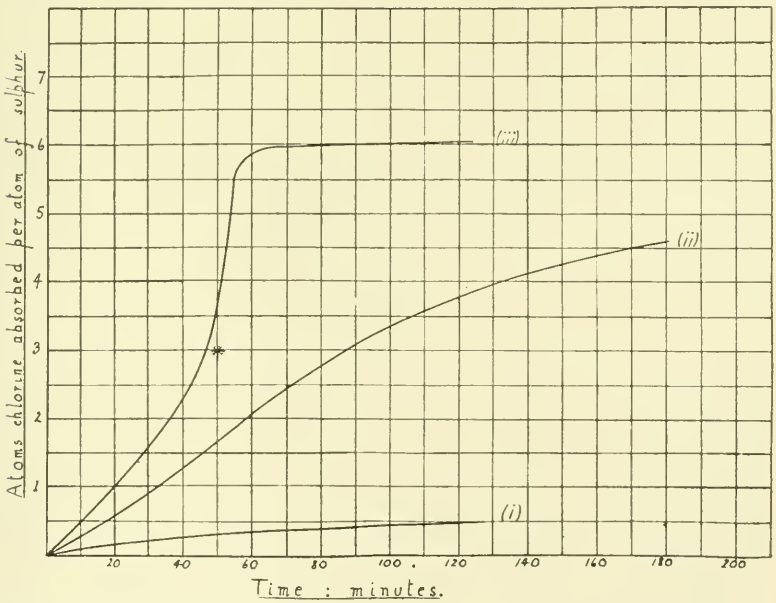
On this assumption, added sodium hydroxide will displace the equilibrium to the left, dilution will move it to the right, and, in accordance with the observed facts, the solution will be stabilised or activated, respectively.

In considering the oxidation of sulphur compounds by hypochlorite, it is convenient to commence with the action of sodium hypochlorite on sulphides. The latter (provided the hypochlorite is sufficiently active when a higher member of the sulphide series is being dealt with) are quantitatively oxidised to sulphones. No traces of any intermediate compounds appear to be formed and hypochlorite is without further action on the resulting sulphones. Four atoms of available chlorine are absorbed for each sulphur atom oxidised. The alkalinity of the hypochlorite does not change appreciably during the reaction. The lower sulphones are more soluble in water than in light petroleum and are found chiefly in the spent aqueous reagent. With increase in molecular weight the resulting sulphone tends to remain in the oil, being more soluble therein than in water; the sulphur content of the oil therefore remains unaltered. Thus although diethyl sulphone is practically insoluble in petroleum and readily soluble in water, the reverse is true of di*iso*amyl sulphone. Sulphones are very high boiling and are left as residues if gasolene containing them is distilled. Sulphones of intermediate molecular weight, *e.g.*, dipropyl and di-*so*butyl sulphones, can be gradually removed from the petroleum layer by water washing.

The rate of oxidation of sulphides, particularly the lower members, is only slightly affected by the alkalinity of the hypochlorite. The effect is very small, large quantities of free alkali being required to prevent the oxidation occurring within a comparatively few minutes.

The primary oxidation products from a disulphide, unlike those from a sulphide, are acidic, *i.e.*, the sulphonic acid together with a smaller quantity of sulphuric acid; these appear in the aqueous

layer as their sodium salts. The formation of sulphuric acid is surprising; since sulphonic acids are not further attacked, it must be formed directly from the disulphide. The gradual neutralisation of the free alkali by the acidic products makes it necessary, in describing the effect of alkalinity on the reaction, to distinguish between two somewhat different cases. (1) The free alkali present is more than equivalent to the total possible acid products; the reagent will then always remain alkaline. (2) The free alkali is less than equivalent to the total possible acid products; if the reaction is continued long enough the reagent will become acidic. The reaction under the first condition may be described as the normal one. Plotting atoms of available chlorine absorbed per atom of sulphur originally present as diethyl disulphide against time, curves are obtained of which (i) for a strongly alkaline and (ii) for a weakly alkaline solution are typical. The influence of the added alkali hydroxide is very marked. If, however, the alkalinity of the reagent is so chosen that it falls into the second class, the additional complication causes the absorption-time curve to assume quite a



different form (iii). The initial part of the reaction takes the normal course until the acidic primary products have completely neutralised the free alkali present; at that point (*) there occurs a very rapid absorption of available chlorine which continues until the sulphur

compound is entirely removed from the petroleum solution, the reaction then tails off and, finally, a slow spontaneous decomposition of the residual dilute acid hypochlorite continues to take place. A considerable evolution of heat occurs at and immediately after the point in the reaction marked (*); the oxidation at this stage is so rapid that it is impossible to isolate any intermediate compounds.

Although the reaction is considerably slowed up by the addition of even a little alkali, it is interesting to note that even 20 per cent. of sodium hydroxide does not completely inhibit the oxidation.

The apparent course of the reaction between sodium hypochlorite and a mercaptan depends greatly upon the alkalinity of the former. The first action, as stated above, leads simultaneously to the formation of the sulphonic acid, sulphuric acid and the disulphide; the last-named, if the reagent is sufficiently active, is destroyed as it is formed and the acids, as their sodium salts, are the only products. But with a more stable solution of hypochlorite a much slower decomposition of the disulphide occurs and this substance then appears as the chief product, accompanied by smaller quantities of the acids which have been formed, for the most part, by direct oxidation of the mercaptan. The first part of the reaction, in which the mercaptan itself takes part, does not appear to be greatly affected by the alkalinity of the reagent, whilst the factors which influence the destruction of the resulting disulphide are those which govern the normal interaction of this type of compound with sodium hypochlorite. The oxidation may be represented diagrammatically thus:

$$\begin{array}{ccc} & \nearrow \; H_2SO_4 \; \leftarrow & \\ RSH & \longrightarrow & R_2S_2 \\ & \searrow \; RSO_3H \; \swarrow & \end{array}$$

As stated above, by the action of sodium hypochlorite on hydrogen sulphide, sulphur and traces of sulphuric acid are produced. Part of the sulphur becomes dissolved in the oil; this emphasises the necessity for a preliminary soda-wash on any distillate which is likely to contain hydrogen sulphide and which is to be hypochlorited. Since sulphur is not attacked by hypochlorite solutions the sulphuric acid must be formed directly from the hydrogen sulphide.

It was found that thiophenes were not attacked by sodium hypochlorite, at least not under the conditions employed.

Alkaline Hypochlorite Treatment

The hypochlorite solutions employed for desulphurisation are

prepared in such a form that, although highly reactive, they are not sufficiently unstable to decompose and cause chlorination. At one stage in the development of the process, various methods were actually employed to reduce the alkali content during the treatment, thus increasing the activity of the reagent and reducing the time of treatment. It was found that the reduction could be effected by the addition of salts of such metals as iron, copper,* etc., as well as by passing flue gases into the washer. The process was, however, risky and was abandoned. Hypochlorites have also been used for treating paraffin wax, the treatment being carried out slightly above the melting point of the wax. The application of the hypochlorite desulphurisation process to cracked spirits reduced the stability of the finished products and caused a certain amount of chlorination or more probably chlorhydrin formation. It was found that this difficulty could be avoided provided the hypochlorite process was only used to sweeten and not to desulphurise completely.[10] Complete desulphurisation is unnecessary for it is usual to treat with acid to polymerise reactive bodies present in the oil, and the acid can be used to effect both polymerisation and desulphurisation. It follows from the explanations given above of the mechanism of the process that if sufficient alkali is present the oxidation by the hypochlorites can be limited mainly to mercaptans although, of course, some of the other sulphur compounds are attacked to a slight extent. In other words, the hypochlorite processes can be made comparable with the plumbite process and used to effect sweetening of cracked spirit. At the same time the addition of alkali reduces the free hypochlorous acid content and therefore reduces the chlorhydrin formation. When used for sweetening cracked distillates it is applied before the acid treatment. The alkaline hypochlorite treatment has now been further developed and is used for sweetening straight-run spirits which it is not intended to desulphurise. Only sufficient hypochlorite is used to effect this sweetening, thus limiting the action to mercaptans and economising in hypochlorite.

The hypochlorite process has several advantages over the plumbite process for sweetening; of these the most important is that there is no lead sludge to be recovered, the completely spent hypochlorite being passed directly into the effluent.

Acid Washing

Acid washing is employed to (*a*) reduce sulphur content, (*b*) remove

* The use of copper hypochlorite was patented in America.

basic substances (*e.g.*, nitrogenous bases such as exist in Californian petroleum, (*c*) polymerise the more reactive gum-forming substances present in unrefined cracked spirit or unrefined kerosene.

The action of sulphuric acid in reducing the sulphur content of light distillates is mainly physical, the sulphur compounds being dissolved owing to their greater solubility in the acid, but oxidation and sulphonation also occur. Thus Wood, Sheeley and Trusty[6] have shown that mercaptans are readily oxidised by 98 per cent. acid, although acid of lower concentration has no oxidising action. The sulphur dioxide formed simultaneously from the acid must be removed from solution in the oil by soda-washing after the acid treatment. Fuming sulphuric acid (20 per cent. SO_3) has an even greater oxidising effect, chiefly of course because it does not so soon fall below the concentration (66 per cent.) at which the acid becomes ineffective. For a similar reason the solvent action is also greater; with increasing dilution of the acid the solvent action decreases, and practically ceases when the concentration falls to about 70 per cent. It is chiefly for this reason that distillates to be acid treated are generally given a preliminary treatment with a small quantity of acid or of spent acid from a previous batch. Sulphuric acid treatment, therefore, lends itself particularly well to counter-current washing.

Although sulphuric acid oxidises a mercaptan mainly to the disulphide as shown by Wood, Lowy and Faragher,[11] a certain amount of the disulphoxide is formed and probably the sulphonic acid; traces of compounds are also formed which apparently give free sulphur by thermal decomposition, since copper sulphide is formed on heating with copper (the authors hope to publish their work on this subject at an early date).

Free sulphur is formed by the oxidising action of sulphuric acid on hydrogen sulphide; it is therefore essential that the latter should be removed previous to acid treatment. Sulphuric acid has no action upon free sulphur in petroleum solution.

Sulphuric acid exerts a solvent action on sulphides, either open-chain or cyclic ("thiophanes"), although according to Wood, Lowy and Faragher slight oxidation occurs. The solvent action is very pronounced, quite a small volume of 98 per cent. acid being sufficient to effect a complete extraction of the lower sulphides. Youtz and Perkins,[12] however, found that although alkyl sulphides and more particularly those of low molecular weight or secondary sulphide are readily removed, the higher sulphides, *e.g.*, diphenyl or dibenzyl sulphides, are much less readily extracted. Fuming

sulphuric acid exerts an even greater solvent action. Sulphoxides and sulphones (probably also disulphides) are similarly removed unchanged by the purely solvent action of the acid. Any of these substances may be recovered by diluting the acid, a convenient method of isolation adopted, for example, by Thierry.[13]

The solvent action of sulphuric acid on disulphides is much less marked than with sulphides. The solvent action decreases rapidly with dilution of the acid and with increasing molecular weight of the disulphide. The oxidising action is slightly greater than with sulphides (Wood, Lowy and Faragher).[11] Free sulphur is not formed by the action of sulphuric acid on either sulphides or disulphides.

Thiophene and its derivatives are fairly easily removed by sulphuric acid. According to Wood, Lowy and Faragher[11] the desulphurising action of the acid on solutions containing thiophene is due to the formation of the thiophene sulphonic acids, although some oxidation occurs as shown by the formation of sulphur dioxide. From the work of these authors it would appear that the action is chiefly sulphonation, but in view of the results of Youtz and Perkins[12], who found that both trimethyl- and tetramethylthiophene are removed by the acid, this theory must be modified. It is, therefore, probable that desulphurisation is due to both chemical and physical action.

Sulphuric acid has a similar action upon phenols, should these be present in a petroleum distillate; sulphonation occurs, the resulting sulphonic acid being dissolved in the acid layer.

During the removal of sulphur compounds by acid washing a certain quantity of aromatic hydrocarbons is also removed. The authors have found that on diluting "acid tar"[14] from the acid treatment of kerosene the oil produced was highly aromatic. It is of interest that these hydrocarbons were present in the tar as such and not as the sulphonic acids. The solvent action may have been due to (i) sulphonic acids, which would remain in the aqueous layer on diluting the tar, (ii) sulphur dioxide, or (iii) organic sulphur compounds in the tar. That sulphonation of aromatic hydrocarbons may be brought about by 98 per cent. acid is shown by the presence of diphenyl sulphone in "benzol," which has been acid treated:

$$C_6H_6 + H_2SO_4 \rightleftharpoons C_6H_5SO_3H$$
$$C_6H_6 + C_6H_5SO_3H \rightleftharpoons C_6H_5SO_2{\cdot}C_6H_5.$$

It was probably for this reason that the present authors found that after removing the sulphur compounds (by means of sulphuric

acid) from the oil produced on diluting "acid tar" the sulphur content of the residual oil could not be further reduced.

The action of sulphuric acid in removing basic substances from petroleum is a solvent one, following salt formation. Sulphonation or oxidation are unlikely to occur.

The action of sulphuric acid in removing sulphur compounds, etc., may be summarised as follows:

Compound.	Product in oil layer.	Product in acid layer.
Mercaptan R.SH	R_2S_2 (traces of unstable sulphur compound?)	$R_2S_2O_2$, (RSO_3H?),
Hydrogen sulphide H_2S	S	—
Sulphide R_2S	—	R_2S
Disulphide R_2S_2	—	R_2S_2
Thiophene C_4H_4S	—	$C_4H_3S.SO_3H$
Sulphur S	S	—
Sulphoxide R_2SO	—	R_2SO
Sulphone R_2SO_2	—	R_2SO_2
Alkyl sulphate R_2SO_4	—	R_2SO_4
Bases	—	as sulphate.
Phenols	—	partly as phenol, partly as sulphonic acid.

Untreated distillates containing unsaturated hydrocarbons tend, on storage, to develop a peculiarly unpleasant "rancid" odour, go off colour and eventually deposit an oil-insoluble viscous gum. This action is accelerated by light and air. Very little is actually known of the processes involved, although both oxidation and polymerisation play an important part. As these gums are not volatile they are deposited in the intake system of the engine, in which the spirit containing them is burnt, and they become converted into carbonaceous material by the heat. Similarly kerosenes containing gum-forming substances char the wick very rapidly and burn badly. It is therefore essential either to remove or considerably lessen the formation of gum. In practice this is generally carried out by polymerising the more easily polymerisable constituents.

Sulphuric acid is one of the cheapest and most convenient polymerising agents known. It has been used for some years for the refining of cracked gasolene and for many years for refining kerosenes containing unsaturated hydrocarbons. Owing to the redistillation process which it necessitates, as well as the losses in the form of polymers, it is a wasteful refining agent for gasolenes. It has, however, many advantages.

Although for many years chemists have studied the action of sulphuric acid on olefines, particularly the lower members, very little is yet known of the actual mechanism of the polymerisation process.

Until the work of Brooks and Humphrey[15] was published, the generally accepted view of the refining action of the acid on cracked spirits was that the olefines were polymerised to tars, sulpho-acids formed and the olefines completely removed. Actually, of course, only a fraction of the olefines are polymerised. The results obtained by these authors can be summarised as follows:

(*a*) The principal results of acid treatment are polymerisation, formation of secondary and tertiary alcohols and mono- and di-alkyl esters. None of the simple olefines give tars with the concentrated acid at 15°C.

(*b*) The tendency to polymerise increases with increasing molecular weight.

(*c*) The polymerisation products formed are more stable than the parent olefines and are generally found dissolved in the oil layer. A polymer formed from two molecules of a mono-olefine only contains one double bond.

(*e*) Diolefines form tars.

The accepted theory for the mechanism of polymerisation, that a molecule of the acid alkyl ester and one of unsaturated hydrocarbon react with elimination of the acid molecule, is not borne out by the results obtained by Norris and Joubert.[16] These authors working with the five possible pentenes found that polymerisation takes place with four of the five more readily when the acid ester is not formed, and that it probably results from the removal of water from the alcohol first produced. Four amylenes were found to pass completely into solution either as alcohol or ester before polymerisation commenced. The formation of the dimeride from trimethylethylene is explained as follows:

$$C_3H_5(CH_3)_2C(OH) + H\ .\ C(CH_3)\ C(CH_3)_2$$

$$\qquad\qquad\qquad\qquad\qquad\qquad H \qquad OH$$

$$= \quad C_2H_5(CH_3)_2C.C(CH_3) = C(CH_3)_2 + 2H_2O$$

When a secondary alcohol is formed by the action of the acid, more concentrated acid is required to bring about polymerisation than if a tertiary alcohol is formed. This is not surprising, as tertiary alcohols are more easily formed and decomposed than the corresponding secondary alcohols.

The extent to which polymerisation occurs is largely dependent on the concentration of acid employed, concentrated acid giving a higher polymeride than acid of lower concentration.

Although acid treatment followed by distillation reduces the

gum-formation and increases stability, it does not render the oil completely stable.

Cracked distillates produced under comparatively mild conditions are more easily refined than those produced by drastic cracking. Thus liquid-phase cracked distillates can be refined by a small acid treatment followed by redistillation to remove the high boiling products which would change the final boiling point; vapour-phase cracked products, however, react almost explosively with small quantities of acid and the losses through polymerisation are enormous. This difference is due mainly to the larger proportion of reactive olefines in the latter product as well as the higher diolefine content.

Diolefines polymerise very much more rapidly than mono-olefines and the polymerisation proceeds to a great extent. They are, moreover, readily polymerised by dilute acid. Thus, when cracked gasolene containing diolefines is treated with acid, they are at once polymerised with the more reactive mono-olefines and are left behind on distillation.*

It is generally considered that this removal of diolefines is necessary because these substances are supposed to be the cause of gumming in an unrefined or badly refined cracked spirit, either when the spirit is kept or when it comes in contact with the hot inlet valve stems of an engine. The fact that such gum formation admittedly occurs makes it essential that the most reactive constituents of an unrefined cracked distillate should be removed. It is, however, by no means certain that diolefines are the sole or even the main cause of polymerisation, since many of the low boiling individual substances of this class do not undergo polymerisation with any particular ease on keeping (*cyclo*pentadiene is one of the exceptions). Actually conjugated diolefines, when they are present, form a highly valuable part of a cracked spirit. Thus both butadiene and $\alpha\gamma$ dimethylbutadiene† are very effective anti-detonating agents, both being definitely more effective than the same proportion of benzene. This, of course, explains to a large extent the fall in anti-detonating qualities when vapour-phase cracked distillates are acid treated, although the removal of certain mono-olefines (such as tri- and tetramethylethylene) by polymerisation also has this effect. The quite common supposition that the polymerides of olefines act as pro-knock agents is fallacious. Thus, the dimeride

* Although the higher boiling polymers are left behind on distillation, the lower boiling polymers pass into the distillate.

† Diallyl produces comparatively little effect.

of trimethylethylene obtained by the action of acid has almost the same anti-detonating action as benzene. It is evident that acid treatment of cracked distillates is a wasteful procedure, since not only is material lost, but the H.U.C.R. of the refined oil, and therefore its value, are lowered.

As indicated above, besides causing polymerisation, sulphuric acid reacts additively with olefines forming alcohols, alkyl-sulphuric acids or their esters. Alkyl-sulphuric acids remain in the acid layer, but the esters are partly dissolved in the spirit and become decomposed when this is redistilled; in the presence of steam hydrolysis occurs with formation of free acids which are highly corrosive. This shortens the life of the plant. It is therefore essential that a cracked distillate which has been acid treated should receive a thorough water wash and soda treatment to hydrolyse and remove alkyl-sulphuric esters.

Quite recently it has been found that polymerisation may be considerably reduced and solvent action upon sulphur compounds substantially retained by the use of 98 per cent. sulphuric acid at comparatively low temperatures (Halloran[17] suggests 15°F. as suitable). The acid tar produced is said to be light in colour and quite fluid.

Cuprammonium Sulphate[18]

This reagent has been used in aqueous solution by the Houston Oil Company, of Texas, for the refining of cracked distillates. It is prepared by adding caustic soda to copper sulphate solution until all the copper is precipitated as hydroxide. This is redissolved by adding ammonia, the resulting "blue solution" then being ready for use. It is claimed that this solution is capable of removing mercaptans and disulphides as well as acetylenes and diolefines. Although the removal of the mercaptans and acetylene as mercaptides and acetylides respectively is understandable, it is not clear how this solution can react with either diolefines or disulphides. It is stated that ammoniacal silver solutions act in a similar manner.

Liquid Sulphur Dioxide—Edeleanu Process

Aromatic or unsaturated hydrocarbons are much more soluble in liquid sulphur dioxide than are paraffins or *cyclo*paraffins. Thus, benzene, toluene, the xylenes and mesitylene are completely miscible with liquid sulphur dioxide at −10°C. whilst pentane, hexane, octane, nonane and decane are practically insoluble at −18°, the lower members being soluble to about 1·8 per cent. at −10°. Amylenes are completely miscible at −10° or −18°, *cyclo*Hexane is insoluble

at $-18°$, and soluble to the extent of 3 per cent. in an equal volume of sulphur dioxide at $-4{\cdot}5°$; the higher naphthanes are less soluble.[19] It has been shown by de Casli[20] that compounds are actually formed between sulphur dioxide and toluene, mesitylene, ψ-cumene, ethylbenzene, cymene or tetrahydronaphthalene, which no doubt accounts for the bright yellow colour which is at once produced when sulphur dioxide is mixed with kerosene; it is, however, probable that the action of the sulphur dioxide is mostly one of physical solution.

Edeleanu has developed a refining process based upon these facts, which was designed in the first place to remove the unsaturated and aromatic constituents that cause Roumanian kerosene to burn with a smoky flame. Kerosene, for example, is agitated with an equal volume of liquid sulphur dioxide at 15°F. After settling, the lower layer of sulphur dioxide containing the more soluble constituents of the kerosene is withdrawn and the sulphur dioxide distilled off by the application of heat under reduced pressure. The upper layer consisting of the less soluble constituents of the kerosene contains some sulphur dioxide, from which it is freed in a similar manner. Care must be taken to exclude moisture, which leads to corrosion of the plant. The sulphur dioxide is condensed and used again.

The degree of separation obtained is determined by the temperature at which the operation is carried out. This is due to the miscibility of the paraffins and liquid sulphur dioxide, which decreases with decrease in temperature. Thus in the neighbourhood of $-80°$C. the separation is so good that the process can be used to estimate aromatic hydrocarbons; such low temperatures are, of course, impracticable on the large scale and the operation is usually carried out between 15° and 30°F. At these temperatures the separation is far from complete, the aromatic hydrocarbons in the sulphur dioxide layer exerting a considerable solvent action upon the non-aromatic hydrocarbons, whilst the sulphur dioxide in the latter tends to re-extract the aromatic hydrocarbons from the sulphur dioxide. Nevertheless the dissolved portion of the oil contains a large part of the original aromatic constituents; valuable anti-detonating material may, therefore, be obtained from it by topping and cracking the remainder.

Sulphur compounds are also extracted by the sulphur dioxide, but again the separation is by no means complete. This extraction is purely physical, no evidence existing for the formation of sulphur compound—sulphur dioxide compounds.

The process does not lend itself to the treatment of gasolene owing to the difficulty of separating the low boiling constituents from the sulphur dioxide.

SOLID REFINING AGENTS

The Frasch Process

In this process, probably one of the earliest refining processes devised, but now practically obsolete, the vapour of the distillate to be treated was passed over heated copper oxide. The latter acts, at least partly, as an oxidising agent; after use it may be regenerated by heating in a current of air. The reagent has no appreciable action on free sulphur, carbon disulphide, sulphoxides, sulphones, thiophene, alkyl-sulphides or alkyl-disulphides. Its sweetening influence is due partly to its action on hydrogen sulphide, but more to its effect on mercaptans. A copper mercaptide is formed primarily, this reaction no doubt explaining the effectiveness of the Frasch process on Ohio and Canadian oils. By more prolonged action, the copper mercaptide reacts with more cupric oxide giving cuprous oxide and the alkyl-disulphide. According to Wood, Lowy and Faragher[11] solid copper mercaptide undergoes thermal decomposition, giving cupric sulphide and the alkylsulphide. These authors also point out that copper mercaptides are in general less soluble in petroleum distillates than the corresponding lead mercaptides.

Anhydrous Aluminium and Zinc Chlorides[6, 12]

Anhydrous metallic chlorides are used mainly as polymerising agents for the treatment of cracked distillates. Aluminium, and probably to a lesser extent zinc chloride, also exert a desulphurising action. Thus Youtz and Perkins found that when naphtha solutions containing various sulphur compounds were gently refluxed (roughly 120°C.) with a limited amount of aluminium chloride, all the compounds tried reacted to a greater or lesser extent. On distillation, further reaction takes place probably owing to the higher temperatures involved. It is possible that compounds are found with the aluminium chloride and that on further heating these are decomposed. It was found that, although ethyl sulphide was little affected by the treatment, the disulphide was very thoroughly decomposed with the formation of some hydrogen sulphide and a considerable quantity of mercaptan; after distillation all the sulphur remaining was removed by plumbite, giving a yellow precipitate only, *i.e.*, no hydrogen sulphide was present. A very striking difference was found between the behaviour of N-*sec*-heptyl sulphide and the

N-heptyl sulphide, the latter being very little affected even on distillation, whereas the former decomposed on refluxing. Nearly all the compounds were completely decomposed by larger amounts of aluminium chloride.

Apart from its desulphurising action, aluminium chloride is a very energetic polymerising agent for unsaturated hydrocarbons, even at ordinary temperatures.

Thus Aschan obtained naphthenic hydrocarbons, such as *cyclo*-hexane, by treating amylenes with the anhydrous chloride. Naphthenic acids are also polymerised. Aluminium chloride is also very effective in removing colour, and oils refined with it are extremely resistant to aerial oxidation. Zinc chloride has recently found favour for the refining of vapour phase cracked gasolene. It is a milder polymerising agent than aluminium chloride, and is generally employed deposited on pumice (from alcoholic solution) at a temperature of 150°C.

BAUXITE

Bauxite, which is a naturally occurring form of hydrated aluminium oxide, is generally employed to remove colour or sulphur from light petroleum distillates, particularly kerosene. It is, however, also used for decolourising wax which is filtered hot. It is generally used in a coarsely-powdered form (70 to 80 per cent. passing through a 30 to 90 mesh), which is particularly suitable for filtration. Previous to use it is heated to between 400° and 500°C. and allowed to cool; after use it may be recovered indefinitely, the only loss being due to disintegration. Heated to temperatures over 600° it loses its adsorptive power. Although cold filtration, for example, at −10°C., gives better sulphur adsorption than between 50° and 100°C., it is usually employed while still warm. The reason for this is that it is essential not to keep bauxite too long after roasting as it rapidly absorbs moisture from the air and loses its adsorptive power. If kept in a dry atmosphere it can be stored indefinitely after roasting. When the oil comes in contact with the bauxite the heat of wetting is considerable; in fact if the bauxite is heated and allowed to cool in a vacuum the heat of wetting is so great that cracking may actually occur. Adsorption of colour takes place more rapidly than sulphur removal, the removal of the latter being due both to adsorption and oxidation. Thus Remfry has found that the sweetening effect of bauxite is in part due to the oxidation of the mercaptans to compounds of higher molecular weight (*i.e.*, disulphides) by the air occluded in the bauxite; the latter are then

removed by adsorption. As low boiling sulphur compounds cannot be easily removed by adsorption, the oxidation explains the desulphurising action of bauxite. Chowdhury and Bagchi,[21] working with aluminium gel (water content 6 per cent.) activated by igniting aluminium hydroxide at 350 to 400°, found that compounds containing sulphur in an oxidised form were more readily adsorbed, and that absorption could be rendered more complete by a preliminary oxidation by the passage of air in the presence of alumina gel. Free sulphur is not removed. The colour adsorption continues for some considerable time after the sweetening action has ceased. Wood, Sheeley and Trusty[6] have worked with aluminium oxide roasted at 1,000°C., but they do not state the form of oxide employed. This temperature is well above that employed for bauxite, which would be rendered useless by such treatment. These authors found that the oxide used partly removed *iso*amyl mercaptan and dimethyl sulphate but had little or no effect on free sulphur, hydrogen sulphide, carbon disulphide, thiophene, *n*-butyl sulphide, *n*-propyl disulphide, diphenyl sulphoxide, methyl *p*-toluenesulphonate or *n*-butyl sulphone. Besides removing colour and sulphur compounds bauxite has been used to effect polymerisation in much the same way that fuller's earth is used. Remfry found that cracked spirits could be refined by redistillation after filtration through bauxite, the high boiling polymerides being left behind.

Silica Gel

Silica gel is similarly employed for desulphurising and sweetening sour distillates. It also removes colour. Although Wood, Sheeley and Trusty[6] attribute the sweetening action to the ease with which silica gel adsorbs mercaptans, it is highly probable that it is very similar in action to bauxite, sulphur compounds being removed by a combination of adsorption and oxidation. The same authors obtained more favourable results with silica gel than with alumina, but as the most effective type of alumina, that is properly roasted bauxite, was not used for their tests, the results cannot be considered when comparing bauxite and silica gel. Youtz and Perkins[12] found that of the sulphur compounds examined by them the higher substituted thiophenes were the least easily removed.

Fuller's Earth and Floridin

Both fuller's earth and floridin are used to remove colour from petroleum distillates. Before use they are heated between 250° and 300° to remove excessive moisture. When cold they are used in the same way as bauxite, that is, the oil is allowed to filter through

a thickness of the material until the colour adsorption drops below a predetermined figure.

Wood, Sheeley and Trusty[6] found that fuller's earth at ordinary temperatures possessed no sweetening action, but that it was capable of adsorbing sulphur compounds of fairly high molecular weight. Thus it removed dimethyl sulphate, methyl *p*-toluenesulphonate, diphenyl sulphoxide and *n*-butyl sulphone from naphtha solution more readily than the specimen of alumina tested. Like bauxite, fuller's earth is incapable of removing free sulphur. The refining action of both fuller's earth and floridin is therefore probably entirely physical.

Besides being used as filtration media, both fuller's earth and floridin are used as vapour-phase refining agents for cracked distillates owing to their mild polymerising action. The vapour of the oil to be refined is passed over the heated adsorbent at such a temperature that no condensation occurs, *i.e.*, just above the end-point of the distillate, generally about 200°C. Under these conditions the more reactive olefines and, if present, di-olefines are polymerised and separate out as high boiling generally viscous liquids, while the more stable vapour passes on and is condensed. The process has the advantage that the vapours from the dephlegmator of the cracking plant can be passed through the refining agent without condensation and re-vaporising. Some refiners prefer to treat the cracked distillates with acid before passing them through the adsorbent earth, in which case sulphur dioxide is generally formed and must be removed by washing with sodium carbonate to prevent further polymerisation. The sulphur dioxide is undoubtedly due to the decomposition of alkylsulphuric acids and esters.

Youtz and Perkins[12] carried out a few experiments to test the desulphurising action of fuller's earth on the vapours of solutions containing sulphur compounds. The tests were carried out at 400°C. Their results were inconclusive but indicated that ordinary sulphides are easily removed, disulphides and secondary sulphides less readily, and thiophenes much less readily removed.

From the fact that the condensates from all the solutions tested were sour, it appears that decomposition besides adsorption takes place. This is, however, not surprising in view of the recent work by Faragher, Morrell and Comay[22], who have found that the lower sulphides, disulphides and mercaptans are all decomposed when passed through a silica tube at 496°C. The results of these authors can be summarised as follows:

	Decomposition Products.
Ethyl disulphide	Sulphur, hydrogen sulphide, ethyl mercaptan, sulphide (probably ethyl), thiophene and hydrocarbons.
n-Propyl disulphide ...	Sulphur, hydrogen sulphide, *n*-propyl mercaptan, sulphide (probably propyl), thiophene derivative (probably 3 : 4 dimethylthiophene) and hydrocarbons.
Ethyl sulphide	Hydrogen sulphide, mercaptan and hydrocarbons.
*Iso*Amyl mercaptan ...	Sulphur, hydrogen sulphide and hydrocarbons (no thiophene or sulphide).
Thiophene	Unaffected.

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ZUSAMMENFASSUNG

Unter dem Druck der öffentlichen Nachfrage werden die Petroleumprodukte, und insbesondere die leichteren Destillate, feiner raffiniert als dies vom reinen Nützlichkeitsstandpunkt aus erforderlich wäre. Hierin liegt eine Verschwendung an Zeit und Material. Es besteht daher heutzutage das weit verbreitete Bestreben, den Begriff des Raffinierens einer Revision zu unterziehen und die Verarbeitung auf das notwendige Mindestmass zu beschränken.

Unter diesem Gesichtswinkel wird eine Anzahl moderner Verfahren betrachtet.

THE COMPOSITION AND CHEMICAL PROPERTIES OF RUSSIAN OILS

RUSSIAN NATIONAL COMMITTEE, WORLD POWER CONFERENCE

PROF. J. ELIN

Paper No. F6

CONTENTS

INTRODUCTION—CRUDE OIL—GASOLINE—KEROSENE—LUBRICATING OILS—MAZOUT (RESIDUUM)—BIBLIOGRAPHY—ZUSAMMENFASSUNG

An exhaustive study of the composition of petroleum offers great difficulties on account of its extreme complexity and the inactive nature of the hydrocarbons of which it is composed. In spite of numerous investigations carried out throughout the world, there is still little accurate data concerning the composition of the principal petroleums and none concerning those of secondary importance.

Among the Russian scientists who have devoted themselves to the study of petroleum, Markovnikoff and Oglobin, Beilstein and Kurbatoff, Zelinsky, Kharichoff, Tikhvinsky, Gerr, Gourvitch and Sakhanoff must be mentioned. The results of their investigations have appeared both in book form and as articles in technical periodicals; from these a considerable amount of valuable data on the properties of many Russian petroleums have been obtained. There still remains, however, much to be done before the problem of the composition of petroleum is completely solved. Some of the difficulties encountered in an investigation of this kind can only be realised when the instance cited by Prof. L. G. Gourvitch is considered. Prof. Gourvitch stated that in order to obtain 37 gm. of pure hexamethylene from 25 Kg. of Galician benzine nine months' work was necessary. Hexamethylene has a comparatively simple constitution—C_6H_{12}—so that the work necessary to isolate any hydrocarbon containing say, thirty carbon atoms would be, if possible at all, enormous.

The petroleums from the principal Russian oil-fields, for instance, those from the Baku oil-fields, are generally classified as "naphthenic oils," as distinct from the American oils, for example, the Pennsylvanian oils, which are referred to as "paraffinic." To classify Russian oils as naphthenic is only partly correct, for, although naphthenes predominate in the lightest fractions from the Baku oils, paraffin hydrocarbons are also present. The converse is true for corresponding fractions from the Pennsylvanian oils.

According to American practice, oils are roughly divided into three classes :—(1) paraffin base oils; (2) asphaltic base oils; and (3) mixed base oils. A. Sakhanoff holds that such a classification, apart from its seeming simplicity, is the only possible and reasonable one because, of all the constituents of petroleum, only solid hydrocarbons (paraffins) and asphaltic substances can be isolated with any degree of accuracy. Moreover, the characteristic properties of a petroleum are generally determined by the preponderance of one type of hydrocarbon. When much wax is present in a crude oil, paraffins predominate in the light fractions, and the heavy fractions contain largely hydrocarbons of low specific gravity. Similarly, asphaltic-base oils yield light fractions consisting, essentially, of naphthenes, and heavy fractions containing hydrocarbons of high specific gravity. Such a statement is not, of course, absolutely true; for example, it does not apply to the crude oil of the Emba region (Dossor), which, from its behaviour, cannot be included in either class.

Crude Oil

The principal Russian oil-fields, which lie on the flanks of the Caucasus mountains near the towns of Baku and Grozny, give roughly 95 to 97 per cent. of the total Russian production. The crude oils from these fields can, with few exceptions, be classified as mixed-base oils. All contain wax, some in almost infinitesimal quantities; and most have a considerable, sometimes very large, percentage of gummy and asphaltic substances. The low sulphur content, which is a valuable feature of all the Russian crude oils, in most cases does not exceed a few tenths of one per cent. Most of them also possess a slight acidity, the maximum being 0.22 gm. per 100 c.c. of petroleum.

The percentage of unsaturated hydrocarbons, as determined by the iodine value (Gubler-Valler) is likewise small, the maximum iodine value not exceeding 6.8 to 7.8 for heavy petroleums, while

it is considerably lower for light petroleums. The percentage of aromatic hydrocarbons in all the Russian petroleums is extremely low. Most have a high content of gummy substances, as determined by the test with concentrated sulphuric acid, ranging from 10 to 30 per cent. for Baku crude oils. Surakhany crude oil (Baku) and that from the Emba region (Dossor) have the lowest percentages of asphaltic substances so far determined, *i.e.*, 5 to 8 per cent. and 4 to 5 per cent. respectively.

Gasoline

Russian oils contain in general a lower percentage of gasoline than corresponding American oils. While the Grozny oils have the highest content—up to 30 per cent. at 200°C.—it ranges from 16 to 25 per cent. for Baku oils (Bibi-Eibat oils of low specific gravity). As these gasolines contain very little boiling below 100°C, it is not possible to market the whole of the distillate boiling up to 200°C. as gasoline, but, by the further development of the natural gas gasoline industry, together with introduction of cracking installations, it is expected that this difficulty will be overcome. At the present time, up to 6.5 per cent. of gasoline, with an end point of 170°C. and containing 30 per cent. boiling below 100°C., is recovered from the Baku crude oils; the Grozny oils yield up to 17 per cent. of gasoline, having an end point of 170°C. for the light product or of 200°C. for the heavy product.

Russian gasolines, especially those from Baku oils, have a high anti-detonating value, owing to their composition, are negative to the "doctor test," and contain very small proportions of sulphur (less than 0.01 per cent.); they, therefore, meet all the specifications for this type of fuel. The steady increase in their export year by year indicates the demand for this fuel. The export for the years 1924-1928 was as follows:—

	1,000 tons
1924-1925	276.0
1925-1926	406.3
1926-1927	599.4
1927-1928 (from Oct. 1, 1927 to April 1, 1928)	286.4

Grozny gasoline contains a large percentage of aromatic compounds, reaching in the fractions boiling up to 100°C. as much as 4 per cent., in the fractions boiling from 100° to 150°C. up to 7 per cent., and in those boiling from 150° to 200°C. up to 12 per

cent.; the anti-detonating properties of this gasoline are dependent upon the content of aromatic hydrocarbons. The Baku gasolines, on the other hand, contain aromatic compounds in smaller proportions, and owe their anti-detonating value to their high content of naphthenic hydrocarbons.

KEROSENE

Kerosene is obtained in quantities varying up to 30 per cent. from the Baku crude oils and 17 to 18 per cent. from the Grozny oils. It is a good illuminant and is being exported abroad in gradually increasing quantities. The yearly export is given below :—

	1,000 tons
1924-1925	390.9
1925-1926	305.5
1926-1927	438.3
First half year, 1927-1928	321.2

Being practically free from sulphur and aromatic compounds, this kerosene possesses high illuminating power when burnt in properly designed lamps. It is necessary that the lamps should be properly designed, on account of the predominance of napthenic hydrocarbons, which require an increased supply of air. Under these conditions it possesses a higher illuminating power than most of the other grades of kerosene on the market.

The following formula has been found by A. N. Stepanoff, to give the feed of the lamp wick :—

$$Q = \frac{H-h}{2dH^2h} \cdot \frac{a^2}{Z}$$

where Q = the feed of the wick,
H = the maximum rise of kerosene in the wick,
h = the distance to the top of wick above the kerosene level in the lamp,
d = specific gravity of the kerosene,
a = capillarity constant of the kerosene,
Z = the internal friction of the kerosene.

The specific gravity ranges from 0.820 to 0.826, and has little effect on the burning of kerosene, even if taken in wider limits—0.760 to 0.860. American kerosenes have a specific gravity ranging from 0.790 to 0.800 (Pennsylvanian), 0.805 to 0.819 (Mid-Continental) and 0.823 to 0.833 (Californian).

The capillarity constant is approximately the same for all kerosenes (the variation from the average value of 30 dynes per cm.^{2} not exceeding 10 per cent.). Its influence on the burning may be neglected.

The internal friction considerably influences the burning, for, according to the Stepanoff formula, the quantity of kerosene flowing up the wick is inversely proportional to the internal friction. The latter is approximately four to five times less for light kerosene fractions boiling from 260 to 270°C. than for the higher fractions, and it is therefore essential to keep the percentage of high boiling fractions as low as is reasonably possible. The internal friction of the high boiling fractions for kerosene obtained from different petroleums varies with the source of the petroleum, the specific gravities and boiling points being the same. For example, the fraction of the Grozny paraffinless petroleum boiling from 260 to 270°C. has an internal friction equal to 0.0373 at 23°C., while that for the corresponding fraction of a paraffin base petroleum is only 0.0277.

The above properties of kerosene are given here in order to correct a wrong impression; that is, that the lower the specific gravity of a kerosene the better its quality. Other more important factors than its gravity determine the value of kerosene as an illuminating material. Again, the fact that one kerosene is darker in colour than another does not necessarily mean that the lighter kerosene will burn better. Both may burn equally well. It is, therefore, not safe to assume that because a kerosene is darker than another it must be less valuable for illuminating purposes.

The iodine value of Russian kerosene is very small (less than 1), while the percentage of *aromatic hydrocarbons* is insignificant.

The sulphur content is much lower than the American standards, which allow a sulphur content of 0.10 to 0.12 per cent. The Russian kerosenes, like the best Pennsylvanian kerosenes, have a maximum sulphur content of 0.03 per cent.

The percentage of naphthenic and thionaphthenic acids or their salts is extremely small. As no wax is present in the export kerosene, no cloud is formed at low temperatures and it burns well.

Lubricating Oils

Russian lubricating oils have been well known for many years.

They are manufactured from special grades of Baku petroleums produced in the Balakhany-Sabunchy-Ramany fields, having the following characteristics :—Specific gravity 0.864 to 0.883; Engler viscosity E_{10}=3.81, E_{20}=2.51, E_{30}=2.007, E_{40}=1.77, E_{50}=1.58; asphalt 12 to 18 per cent.; Conradson coke test 0.8 to 1.1; acidity 0.08 to 0.16; iodine value 2 to 2.3; sulphur 0.09 to 0.1; wax nearly 0.5 per cent. Their composition is as follows :—

Gasoline, b.p. up to 150°C., 6 per cent.
Kerosene, b.p. 150 to 275°C., 30 to 32 per cent.
Gas oil, b.p. 275 to 300°C., 5 to 7 per cent.
Residuum, b.p. above 300°C., ca. 55 to 60 per cent.

The specific gravity of the residue is 0.912 to 0.914; its flash point (Pensky-Martens) 153°C.; asphalt 24 per cent.; viscosity E_{50}=9; it does not solidify at 20°C. This residuum is used as raw material for manufacturing lubricating oils.

The valuable properties of the petroleums described above—low acidity, small sulphur content, low percentage of unsaturated hydrocarbons as well as wax—render it possible to prepare lubricating oils ranging from middle lubricating oils to bright cylinder oils from the residuum. They are obtained by distillation using a slight vacuum and introducing large quantities of superheated steam; the distillates need little treatment. Great difficulties, however, are encountered in manufacturing steam-cylinder oils on account of the unsaturated nature of the hydrocarbons present.

The export of lubricating oils is given below :—

	1,000 tons
1924-1925	102.4
1925-1926	140.3
1926-1927	167.8
First half year, 1927-1928	85.0

Only three principal grades of bright lubricating oils are exported. Various blends of these serve to produce a great number of different lubricating oils suitable for most purposes. All blending is carried out in the special oil stores which serve the consumer directly.

The following properties render these lubricating oils particularly valuable : low cold test, very slight acidity, low ash content and iodine value, and low emulsifying tendency.

The physical constants, being well known, are not given here.

By treatment of the above oils with fuming sulphuric acid and

suitable absorbents, excellent grades of white oils are produced, having no odour or taste. These, the so-called medicinal oils, are so far only being manufactured for the home market.

Mazout

Considerable quantities of fuel oil and gas oil are now exported from Russia. The steadily growing export of these products can be seen from the following figures :—

	1,000 tons
1924-1925	426
1925-1926	461
1926-1927	669
First half year, 1927-1928 ...	415.1

Only the best grades of mazout or residuum are exported. They have, as is well known, a high heating value, and are characterised by low viscosity, high flash point, low sulphur content and low acidity.

Before the war no paraffin wax was manufactured in Russia, but recently a large plant has been erected for this purpose in Grozny, with a capacity of 6,000 tons per year. The manufacture of this product from Grozny petroleum presented a difficult problem, owing to the high percentage of asphaltic substances present, together with the fairly high viscosity of the paraffin-bearing fractions. This problem has, however, now been solved.

Another industry which has been re-organised since the nationalisation of the oil-fields is the manufacture of natural gas gasoline in the Baku and Grozny regions. The plants erected in these regions produce up to 35,000 tons of natural gas gasoline yearly. In connection with the recovery of gasoline from natural gas the introduction of the "Tikhvinsky Cycle" on a commercial scale must be mentioned. The principle of this process consists in the use of compressed natural gas for lifting oil in the wells instead of air. Casinghead gas from the well is returned to the gasoline plant (absorbtion or compression type) and then pumped by the compressor into the well; during the lifting process the gas become enriched with gasoline and is returned to the gasoline plant. Thus a cycle is established, the excess of casinghead gas gradually escaping from the well being removed, and the remainder circulated continuously through the system. The advantages of this process are the prevention of gasoline losses through escape of casinghead gas into the air, decreased quantities of emulsified oil,

and finally, no risk of explosions due to the compression of mixtures of gas and air.

Satisfactory results have been obtained by absorbing the gasoline from natural gas by means of ligroin, which is a product boiling approximately between 140 and 200°C. This results in a finished mixture of the natural gas gasoline, with heavier fractions of "straight-run" product. Owing to the similarity of the constitutions of gasoline and ligroin, the absorbtion of the gasoline vapours is fairly complete; the advantage of this process is that it renders the recovery of gasoline from a solvent unnecessary, the mixture obtained being directly blended with "straight run" gasoline, by which means the lacking intermediate fractions are added.

Until recently, the problem of the utilisation of the Grozny paraffin-bearing residuum was perplexing. When, roughly, 40 per cent. of the petroleum has been taken off the residue contains all the wax and asphalt originally present in the petroleum. On account of this wax and asphalt the residuum sets at approximately 30°C. Although the heating value is high, the transportation and the use of such a residuum in a cold climate presents considerable difficulties. These have been overcome in the following manner:—The hot residuum is loaded into insulated tank cars fitted with steam coils, as are also the storage tanks and pipe lines. Given good insulation, it is thus possible to keep the residuum, loaded at, roughly, 90°C., in a liquid state for five days, despite adverse climatic conditions, allowing ample time for transportation. In the future it is hoped that by cracking, the easily decomposed wax will be destroyed, thus producing a residuum of greater fluidity and low set-point.

The present oil production of Russia has reached a total of 11,500,000 tons of crude oil a year. A certain portion of this output is used directly as fuel oil.

Nearly 10 per cent. of the total crude production of the Baku region, namely, the heavy Baku oils having low percentages of gasoline and kerosene, is not distilled, owing to the inadequacy of the refineries. In the future, the capacity of the refineries will be increased sufficiently to cope with the increased production of crude oil, when the whole output will be run to the refineries. Investigations made recently in the Central Chemical Laboratory of Azneft (Baku) have shown that valuable lubricating oils can be manufactured from the heavy crude oils.

A consideration of recent developments in American refining

methods shows that the Russian refineries are out of date, although this was not the case in the past. During the period of European and civil wars, the refinery equipment did not undergo the necessary reconstruction. The cracking process, particularly, remained undeveloped. It is interesting to note that the continuous distillation process was originally developed in Russia, afterwards being adopted in America. The principle of the process is well known; the crude oil flows through a battery of horizontal cylindrical stills placed on a grade, so that by the gradual heating of the crude, fractions are obtained from each still, having progressively higher boiling points. Various products can be obtained by mixing the different distillates.

The principle of the tube still was applied commercially by V. G. Shukoff forty years ago at a Baku refinery then owned by Shibaeff & Co. In this tube still the crude oil is rapidly heated to a definite temperature, which vaporises all the fractions to be removed. The mixed vapours pass through a row of rectifying and fractionating towers and are separated into the required fractions by a process of fractional condensation, thus giving benzine, kerosene, gas oil, etc.

Shukoff's apparatus, which was in operation more than thirty years ago, is now dismantled on account of its age. An apparatus for the destructive distillation of crude oil was also devised and patented by Shukoff in 1890; the scheme of the apparatus is the same as that of Burton. Shukoff's apparatus was not commercially applied on account of the economical conditions which prevailed at that period—there was no demand for either "straight-run" or cracked benzine.

The exportation of petroleum products has been retarded owing to transportation difficulties from the Baku and Grozny regions. Two ten-inch pipe lines are now under construction, one from Baku to Batoum, the other from Grozny to Tuapse, where refineries capable of handling 4.5 millions of tons of the crude oil are being erected.

These new refineries will include the latest improvements in method and plant. Considerable attention has been paid to distillation to obviate the necessity of re-running products, thus lowering fuel consumption, which it is estimated will be as low as 1 per cent. by weight of the crude distilled, assuming the removal of 45 per cent. as distillates, and allowing for the generation of steam. This will be effected by the application of

the process of heat regeneration. Refining losses will be reduced to a minimum by the use of closed systems.

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ZUSAMMENFASSUNG

Der Bericht befasst sich hauptsächlich mit den charakteristischen Eigenschaften der verschiedenen aus Russland ausgeführten Petroleumprodukte. Die beiden wichtigsten Rohöle, von denen diese Produkte gewonnen werden, nämlich die Öle von Baku und von Grozny, werden beschrieben. Beides sind Mischöle von äusserst geringem Schwefelgehalt, aber verhältnismässig reich an Asphaltbestandteilen. Ihre Gasolin-Fraktionen sind in den weniger hohen Siedestufen minderwertig, sodass nur ein Teil der bis hinauf zu 200°C siedenden Destillate als Gasolin verkauft werden kann. Das Baku-Gasolin ist zufolge seines hohen Naphten-Gehaltes als Gegenknallmittel wertvoll; das Grozny-Gasolin besitzt ähnliche Eigenschaften infolge der Anwesenheit von aromatischen Kohlenwasserstoffen. Die Kerosin-Fraktionen beider Rohöle brennen gut und haben eine gute Leuchtkraft. Infolge der enthaltenen Kohlenwasserstoffart benötigen sie eine grössere Luftzufuhr als die meisten andern Kerosine. Der Schwefelgehalt ist sehr niedrig und mit demjenigen der pennsylvanischen Kerosine vergleichbar. Anhand einer von Stephanoff aufgestellten Formel

wird gezeigt, dass das spezifische Gewicht wenig Einfluss auf die Brennbarkeit der Kerosine hat, dass hingegen die innere Reibung ein bei weitem wichtigerer Faktor ist. Diese ist bei höher siedenden Fraktionen viel höher als bei niedriger siedenden. Es wird ebenfalls auf die Unmöglichkeit hingewiesen, Kerosine nach der Färbung zu beurteilen. Die russischen Schmieröle werden aus schweren Rohölen gewonnen, die in der Gegend von Balakhany-Sabunchy-Ramany vorkommen. Diese Schmieröle sind so bekannt, dass eine Beschreibung nicht nötig ist. Der grösste Teil der Rückstände von Baku- und Grozny-Öl findet als Brennöl Verwendung; infolge der ungenügenden Leistungsfähigkeit der Raffinerien wird selbst Rohöl zum Teil zu diesem Zwecke verwendet. Der hohe Wachsgehalt der Grozny-Rückstände gestaltet den Transport schwierig; dies ist nunmehr behoben worden durch den Gebrauch von isolierten und mit Dampfheizung ausgerüsteten Behälterwagen. Bis vor kurzem wurde kein Paraffinwachs in Russland hergestellt, doch ist jetzt eine Anlage gebaut worden, die eine jährliche Produktion von 6 000 t ermöglicht. Das Problem der Herstellung von Wachs aus den Grozny-Rückständen, der bequemsten Quelle, bietet wegen ihres Gehaltes an Asphaltstoffen bedeutende Schwierigkeiten. Diese Schwierigkeiten sind überwunden worden und man hofft, bald zur Ausfuhr von Wachs schreiten zu können. Der Gewinnung von Gasolin aus Erdgas, sowie dem Cracken, wird nach langer Vernachlässigung wieder erhöhte Aufmerksamkeit geschenkt.

Die russichen Raffinerie-Anlagen sind heutzutage veraltet, und die neuen, gegenwärtig in Batum und Tuapse im Bau befindlichen Raffinerien werden auf das allermodernste ausgerüstet werden.

Es wird angenommen, dass der Brennstoffverbrauch bei einer Destillation von 45% weniger als 1% des destillierten Rohöles ausmachen wird.

Die Beiträge russicher Chemiker und Ingenieure zum Wissen über das Petroleum und die Raffinierungsmethoden werden erwähnt.

INVESTIGATIONS IN DISTILLING PROCESSES OF SWEDISH OIL SHALES

SWEDISH NATIONAL COMMITTEE, WORLD POWER CONFERENCE

PROF. B. HOLMBERG

Paper No. F7

CONTENTS

GENERAL—THE ORGANIC COMPOUNDS OF THE SHALE—THE CHEMICAL PROPERTIES OF THE SHALE OIL—PRACTICAL TESTS OF THE SHALE OIL—ZUSAMMENFASSUNG

In Sweden there are abundant deposits of bituminous cambrosilurian shale, which were used from the middle of the 17th century up to the end of the 19th as raw material for the preparation of alum on account of its richness in potash, alumina and iron pyrites; for this reason it is generally called *alum shale*. Owing to its combustible constituents this shale has also been of importance, especially since the end of the 18th century, as a fuel for the burning of lime in districts rich in both shale and limestone, such as Västergötland, Närke, Östergötland and the island of Öland. For the past fifty years the bituminous constituents of the alum shale have, however, attracted a certain amount of attention as potential material for the production of oil and, from the early 'nineties up to recent years, a number of small plants have been erected for this purpose.

In addition to oil, there is the possibility of producing sulphur, potash, etc., from the alum shale, a matter which was very carefully considered in 1913 by a Royal Committee[1] appointed on the initiative of the Riksdag. On account of the increased interest shown in Sweden as in other countries after the Great War, in the possibility of producing the mineral oil requirements at home, the work of

[1] Utredning rörande möjligheterna för en inhemsk tillverkning av mineraloljor svavel m.m ur den i olika trakter av Sverige förekommande alunskiffern, verkställd av därtill av Kungl. Maj:t den 23 maj 1913 tillkallade sakkunnige, Stockholm 1919.

the Committee has, since 1920, been continued by the Swedish Institute of Scientific Industrial Research (*Ingenjörsvetenskapsakademien*), both by examining the different kinds of shale and shale products and by testing the different methods proposed for utilising the alum shale to the greatest advantage. The first-mentioned part of this work has been carried out in the laboratory for organic chemistry at the Stockholm Institute of Technology (*Tekniska Högskolan*) under the author's direction, and it is principally the results obtained in this part of the work which are briefly described below.[2]

The Organic Compounds of Alum Shale

Elementary analyses of samples of alum shale indicate that the organic compounds present contain carbon and hydrogen in the approximate atomic ratio of 1 : 1·2. In addition, the nitrogen content, which varies from 1-2 per cent. of the carbon present, can probably also be attributed to organic material. On the other hand, the large amount of ash present—70 per cent. or more—makes it impossible to give even an approximate figure for the oxygen content. As only a very insignificant amount of water, over and above the water originally present, leaves the shale when it is heated, and, as the oil produced is practically free from phenols and the content of carbon dioxide and carbon monoxide in the distillation gases is inconsiderable, it is probable that the organic compounds of the shale contain very little oxygen. The same probably applies to the sulphur which, in so far as it is possible to judge from available inorganic analyses, seems principally to occur in inorganic compounds, *i.e.*, in combination with iron in the form of iron pyrites. Nevertheless, as the distillation gases contain hydrogen sulphide in considerable quantities and several per cent. of the weight of the crude shale oil often represent organically combined sulphur, it is probable that reactions occur at higher temperatures between the organic compounds and the iron pyrites.

A microscopic examination of ground and polished samples of alum shale shows that the organic and inorganic substances are

[2] With the exception of some investigations completed during the last few years, concerning the value of different deposits of shale from the point of view of oil production, this work has been described in the publications of the Swedish Institute of Scientific Industrial Research (*Ingenjörsvetenskapsakademiens Handlingar*) No. 6 (1922), No. 16 (1923), No. 30 (1924), No. 41 (1925) and No. 56 (1927). A list of references to other work on alum shale is given in the last-mentioned publication. In addition, there is a later work by K. A. Vesterberg in the same series, No. 62 (1927), dealing with the inorganic constituents.

intimately mixed. It has, therefore, not proved possible to concentrate the organic compounds by grinding the finely ground shale with water. Flotation, using turpentine as the medium, concentrated the organic matter slightly, but only to an extent too small to be of any practical use. Attempts were also made to isolate the carbon compounds by treating the finely pulverised shale with liquid sulphur dioxide and with organic solvents such as ether, absolute alcohol, acetone, ethyl acetate, glacial acetic acid, carbon disulphide, carbon tetrachloride, petroleum ether, benzene and pyridine, but the results with raw shale were not promising. A small amount of material can, however, be extracted if the shale is heated beforehand to between 340° and 350° or to roughly 400°, these being found to be the most suitable temperatures; both of these temperatures are, however, sufficiently high to cause deep-seated changes in the organic substances present.

In order to ascertain to what extent the organic compounds can be volatilised before decomposition, distillations were carried out in a vacuum, but even under a pressure of only 0·1 to 0·2 mm. no distillation took place until the temperature was roughly above 300°. As distillation then only occurred with the formation of gas, no substances of any degree of volatility was present until thermal decomposition commenced.

A large number of experiments were made to ascertain the influence of certain factors, such as the rate of heating, the final temperature and the size of the particles of shale, on the pyrolysis or thermal decomposition.

By measuring the quantities of gases formed it was found that there were two maxima for the speed at which decomposition takes place during slow heating, *viz.*, at about 350° and 400°, which approached each other when the heating was carried out at a faster rate, finally coinciding at about 380°; at the higher rate of heating another maximum occurred at roughly 470°. The greater quantity of oil was produced at the lower temperature, but the formation of gas continued long after the production of oil ceased. The content of hydrogen increased with increase of temperature. The slower the increase in the temperature, the smaller the output of oil, but, at the same time, the richer the oil in hydrogen and, therefore, the more valuable. Increasing the size of the shale particles had a similar effect. As examples of the influence of the rate of heating, the following experiments carried out on finely pulverised shale containing 1·35 per cent. moisture, 23·1 per cent. C, 2·5 per cent.

H, 5·9 per cent. S, 0·4 per cent. N and 67·5 per cent. ash, may be mentioned.

When the temperature was increased during thirty minutes to 400° and then, after an interval of sixty minutes, again increased to 500° during another 30 minutes, no more gas was formed and it was found that 100 gm. of shale had given 4,000 c.c. of gas, 3·0 gm. of water, 4·5 gm. of oil and 86·2 gm. of coke residue. An analysis of a sample of the gas collected eighty-five minutes after the heating was commenced gave the following result: 30·4 per cent. H_2S, 5·1 per cent. CO_2, 10·3 per cent. C_2H_4 and other olefines, 0·8 per cent. O_2, 2·8 per cent. CO, 18·0 per cent. H_2, 12·2 per cent. CH_4, 14·5 per cent. C_2H_6 and higher paraffins, and 5·9 per cent. non-combustible residue. After distillation and drying with fused calcium chloride, the oil had $d_4^{21}=0{\cdot}983$ and contained 82·9 per cent. C, 9·1 per cent. H, and 3·0 per cent. S. When washed with caustic soda it gave 1·5 per cent. phenols; the residual oil, on distillation, gave 9·5 per cent. distilling up to 150°, 37·2 per cent. between 150°-300° and 51·9 per cent. residue, the losses being 1·4 per cent. Finally the coke residue contained 19·2 per cent. C, 1·1 per cent. H, 3·7 per cent. S, and 77·3 per cent. ash.

When the temperature was raised to 400° in fifteen minutes and then further increased to 500° in twenty minutes, and then maintained there for ten minutes, the same sample of shale gave 4,240 c.c. of gas, 3·2 gm. of water, 5·7 gm. of oil and 85·7 gm. of coke residue per 100 gm. of shale. A sample of gas, collected after twenty-five minutes, contained: 32·3 per cent. H_2S, 13·3 per cent. CO_2, 1·8 per cent. C_2H_4 and other olefines, 0·2 per cent. O_2, 0·4 per cent. CO, 15·6 per cent. H_2, 35·8 per cent. CH_4, 0·6 per cent. C_2H_6 and higher paraffins, and 0·6 per cent. non-combustible residue. The oil after distillation and drying had $d_4^{20}=1{\cdot}003$ and contained 84·5 per cent. C, 8·95 per cent. H, 2·8 per cent. S, and 1·4 per cent. phenols, etc.; on distillation it gave 6·8 per cent. distilling to 150°, 32·1 per cent. between 150°-300°, 60·1 per cent. residue and 1 per cent. loss. The coke residue contained 18·5 per cent. C, 0·99 per cent. H, 3·8 per cent. S, and 77·9 per cent. ash.

The conversion of the organic compounds in the shale into gas and oil by heat indicates that several different types of decomposition occur. These are more or less complicated by side reactions between the organic and the inorganic constituents of the shale, such as iron pyrites or reducible oxides, or through the catalytic influence of mineral substances. It is, therefore, a hazardous matter to base any conclusions as to the structure of the substances originally

present on the nature of the products obtained by destructive distillation.

Another method of investigating the organic compounds of the shale was, therefore, tried, that is to say treating the shale with chemical reagents, such as alkalies, hypochlorites, permanganate, chromic acid, hydrogen peroxide and nitric acid. Of these the last appears to be of use for converting the organic substances into compounds suitable for further treatment. Thus if the shale, after being oxidised by means of nitric acid, is treated with soda solution, generally only the mineral constituents remain undissolved. It is only when the organic compounds have been thoroughly decomposed, either through the influence of certain geological factors, or artificially, by strong and protracted heating, that carbon in greater or smaller quantities remains undissolved in the soda solution. The sodium salts of the oxidation products are intensely brown in solution and give with mineral acids brown amorphous precipitates of nitro-shale acids, containing carbon, hydrogen, oxygen and nitrogen in the approximate proportions C, 58 per cent.; H, 4·5 per cent.; O, 33 per cent. and N, 4·5 per cent. From the quantitative results and the elementary composition of the nitro-shale acids it appears that the organic compounds in the alum shale are of two fundamentally different types, *viz.*, bituminous and humic substances. Of these the former is more easily decomposed when heated, giving a gas rich in hydrocarbons and hydrogen sulphide, together with a comparatively large amount of oil, and, when oxidised with nitric acid is easily and almost completely destroyed. The humic substances, on the other hand, are the cause of the highest temperature maximum for the formation of gas, giving large quantities of gas rich in hydrogen but hardly any oil in the process; they are oxidised by nitric acid to nitro-shale acids.

It is of interest to note that the Esthonian oil shale, "Kukersit," which on destructive distillation yields a large amount of oil, does not give greater amounts of soda-soluble substances on oxidation with nitric acid in the same way as that adopted for the alum shale, and that the substances obtained are quite different from the nitro-shale acids. It seems, therefore, that the organic material of "Kukersit" may be characterised as bituminous, humic substances hardly being present at all; this is all the more remarkable as the oil obtained from the Esthonian shale is almost as rich in phenols as the low-temperature tar from coal, while the oil from the highly humic Swedish alum shale only contains a few per cent. As this shale was formed at a time when it is unlikely that ligneous plants contributed

to the fossil organic matter in the shale, the name "nitro-shaleacid" has been selected provisionally for the oxidation products until the relationship between these products and the nitro-humic acids, derived from products such as lignite and peat found in formations of later date, has been established.

Although the humic substances of the alum shale have, by treatment with nitric acid, been converted into substances that can be dealt with, no such method has been discovered for the bituminous substances excepting destructive distillation. When it is considered that the oil obtained in this way is strongly unsaturated and almost entirely free from phenols, solid paraffins and solid aromatic hydrocarbons (*vide infra*), that the unsaturated compounds are easily and completely oxidised by nitric acid and that the nitro-shale acids contain carbon and hydrogen in almost the same ratio as the original shale, the conclusion is reached that the same carbon-hydrogen ratio must also apply to the bituminous substances. These substances must, therefore, be looked upon as polycyclic hydrocarbons with a few aliphatic side-chains, probably short and very much branched.

The Chemical Properties of the Shale Oil

Though previous chemical examinations indicated that the hydrocarbons present in the shale oil should be regarded primarily as a definite class of substances intermediate between the terpenes and the benzene hydrocarbons, the presence of small quantities of saturated aliphatic and purely aromatic hydrocarbons, as well as a considerable quantity of organic sulphur compounds, has now been definitely proved in some of the lower fractions. When it is considered that the shale oil originates from material of extreme age geologically, the importance of investigating its composition in great detail becomes evident, partly as a means for discovering a method for qualitative analysis of the oil formed under different conditions, and partly with a view to improving the methods for producing the oil for commercial purposes.

With the object in view of investigating their composition, various samples from the now discontinued small plants have been analysed for unsaturated hydrocarbons, using the ordinary iodine number reagents as well as sulphuric acid of various concentrations. In the first instance we found that when determining the iodine number according to Hübl, it is possible to obtain definite values, although tests with varying amounts of iodine or times of reaction should be made in each case to make sure that a true maximum

value is obtained. Both Wijs' and Hanus' methods, on the other hand, give appreciably higher iodine numbers, but the rate of the reaction is so slow that reliable values are difficult to obtain in a reasonable time or when using reasonable quantities of the reagents.

The behaviour of the different shale oil fractions when treated with sulphuric acid has shown that it affords an excellent means of characterising these fuels, as well as indicating their chemical composition, the possibility of refining them and their practical value generally. As even 75 per cent. acid converts some of the sulphur compounds of the shale gasoline into soluble or high-boiling substances, while the unsaturated hydrocarbons meet with the same fate when treated with 90 per cent. acid, treatment with acid followed by refractionation yields a product which has the original boiling range but which is completely or almost completely saturated to Hübl's reagent. More concentrated acid leads to oxidation, while anhydrous acid hardly leaves any of the original material at all. It should be noted that, as most of the polymerisation products formed by the sulphuric acid treatment do not dissolve in it but remain in the oil layer, the American method of determining the amount of unsaturated substance solely by the decrease in the volume of the oil is far from accurate. If, however, the determination is completed by fractionation of the remaining oil, although much more laborious and demanding larger quantities of material, much more accurate and reliable results are obtainable.

The most detailed chemical examination of Swedish shale oil has been carried out on oil from the trial plant, erected in 1923 by Sven V. Bergh, at Kinnekulleverken, at Kinne-Kleva on the Kinnekulle mountain.[3] This oil formed 4·2 per cent of the weight of the shale distilled and contained 86·0 per cent. C, 10·0 per cent. H, 2.0 per cent. S and 0·4 per cent. phenols. It had the following characteristics:—

Density d_4^{15}	0·970
Viscosity, (Engler) at 20°C.	4·34
at 50°C.	1·75
Flash point (Abel)	21°C.
Calorific value, calorimetric, Kg. cal.	10,100
,, effective ,, ...	9,560

When distilled on a small scale the crude oil gave:—

Fraction b.p., up to	150°	150°-200°	200°-300°	300°-365°	Residue	Losses
Percentage of crude oil	5·3	9·9	27·4	21·0	32·9	3·5

On the large scale, the oil was divided into wider fractions; after

[3] Described by Sven V. Bergh: "A new System of Oil Production from Swedish Oil Shale," The first World Power Conference, No. 122.

washing with dilute sulphuric acid and caustic soda in the laboratory, these were redistilled to give the following products:—

Aviation gasoline	b.p.	Up to 90°C.
Light shale gasoline	,, ...	90°-150°C.
Heavy ,, ,, ,,	... .	150°-200°C.
Shale gas oil	,, ...	200°-300°C.

Fractions with still higher boiling points to be used for the preparation of lubricating oils were given a final treatment.

The *aviation gasoline* was further divided into 5° fractions, 1391 gm. of gasoline giving the following fractions:

Boiling Range	To 35°	35°-40°	40°-45°	45°-50°	50°-55°	55°-60°	60°-65°
Gm.	140	51	24	17	16	57	168
Boiling Range	65°-70°	70°-75°	75°-80°	80°-85°	85°-90°	Residue	Losses
Gm.	490	112	80	54	60	77	45

These fractions possessed the following characteristics:—

Fraction	d_4^{15}	n_D^{20}	% C.	% H.	% S.	% (O+N)	H/C	Iodine No. (Hübl)
Up to 35°	0·6820	1·3810	76·63	13·71	8·84	0·82	2·13	168·6
35°-40°	0·6962	1·3885	75·34	13·02	9·67	1·97	2·06	184·8
40°-45°	0·7105	1·3935	—	—	—	—	—	168·7
45°-50°	0·7105	1·3915	—	—	—	—	—	149·7
50°-55°	0·6993	1·3865	—	—	—	—	—	130·9
55°-60°	0·6862	1·3825	—	—	—	—	—	127·6
60°-65°	0·6793	1·3855	—	—	—	—	—	143·8
65°-70°	0·6981	1·3965	83·79	14·79	0·71	0·71	2·10	143.9
70°-75°	0·7683	1·4275	85·45	12·34	1·44	0·77	1·72	184·9
75°-80°	0·7714	1·4285	85·19	12·16	1·27	1·38	1·70	176·7
80°-85°	0·7362	1·4075	81·92	13·69	0·64	3 75	1·99	155·3
85°-90°	0·7121	1·4005	—	—	—	—	—	132·0

This fractionation shows that the aviation gasoline principally consists of substances boiling at about 35° and 70°, while the figures given in the table for the densities, refractive indices, etc., indicate that the former consisted of roughly 50 per cent. of unsaturated hydrocarbons, probably pentenes (dry aluminium chloride giving no indications of the presence of isoprene) and 25 to 30 per cent. of saturated hydrocarbons (pentane, etc.), while the remainder consisted of sulphur, oxygen and possibly nitrogen compounds. The intermediate fractions, up to the fraction boiling point 65-70°, became less unsaturated with increase in boiling point as shown by the densities, refractive indices and iodine numbers; at and above this fraction the conditions were reversed, probably owing to the presence of hexenes and benzene, together with smaller quantities of hexenes and possibly *cyclo*hexene or the corresponding sulphur and oxygen compounds. Above 80° the benzene and hexenes decrease, with the result that the densities, etc., once more become smaller.

The most important constituents of the lightest distillates of the shale oil are therefore pentenes, hexenes and benzene. The

presence of these substances was definitely established by treating the appropriate fractions with hydrogen bromide, bromine or sulphuric acid. Thus considerable quantities of brom- and dibrom-pentanes were obtained when the fraction boiling up to 35° was treated with hydrogen bromide and bromine respectively; similarly the fraction boiling point 65°-70° gave brom-and dibrom-hexanes. On treating the fraction boiling point 65°-70° with sulphuric acid of 75, 90 and 98 per cent. successively, 66 per cent. remained undissolved; of this only a half consisted of hydrocarbons of the same boiling point as the original material, the remainder consisting of polymers of comparatively low molecular weight. The recovered material was entirely saturated and had an H/C ratio of 2·27 to 1; it, therefore, consisted almost entirely of paraffin hydrocarbons.

The fractions of boiling point 70°-75°, 75°-80° and 80°85° when treated with sulphuric acid, behaved in a similar manner, but the hydrocarbons recovered from the first of these had H/C ratios of 1·85 and 1·89 respectively, indicating the presence of 36 per cent. of benzene, corresponding with 5-7 or 8 per cent. in the original fractions, or practically 1 per cent. of the total gasoline boiling below 90°. The presence of benzene was definitely established by the formation of acetophenone (and its semicarbazone) from the hydrocarbons of fraction boiling point 70°-75° not affected by sulphuric acid. This also was confirmed by treating the acid-insoluble hydrocarbons of the fraction boiling point 75°-80° with chlorsulphonic acid and converting the sulphochloride formed into benzene-sulphanilide.

The *light shale gasoline* was not subjected to any detailed chemical examination, as the prospects of isolating any definite substances were small; in an earlier investigation of the corresponding fraction obtained from the shale by another but similar method small quantities of toluene were identified in the form of the dinitro-compound while *p*-xylol was identified by oxidation to terephthalic acid. The quantities of these substances were, however, very small. Analyses of the crude shale gasoline after treatment with dilute sulphuric acid and caustic alkali gave 84·1 per cent. C, 13·2 per cent. H, 1·16 per cent. S, and an iodine number of 129·7 (Hübl). The characteristics were found to be:—

Density d_4^{15}	0·783
,, d_4^{20}	0·779
Refractive index n_D^{20}	1·4365
Flash point (Abel-Pensky)	1°C.
Viscosity (Engler) at 20°C.	0·94
Calorific value, calorimetric, Kg./cal.	10,880
,, ,, effective	10,160

The Engler distillation gave the following results:—

Fraction b.p.	...	Up to 100°	100°-110°	110°-120°	
Volume in c.c.	...	0·5	6·0	26·7	
Fraction b.p.	...	120°-130°	130°-140°	140°-150°	Total
Volume in c.c.	...	26·2	21·0	12·0	92·4

After treatment of the original *gasoline* with sulphuric acid (75 per cent.) followed by caustic soda (10 per cent.) and distillation with steam, 91·1 per cent. of the original material was recovered. On analysis this gave 85·7 per cent. C, 13·3 per cent. H, 0·68 per cent. S, and an iodine number (Hübl) of 120·7. It had the following characteristics:—

Density d_4^{15}	0·775
,, d_4^{20}	0·770
Refractive index n_D^{20}	1·4345
Flash point (Abel-Pensky)	39°C.
Viscosity (Engler) at 20°C.	0·93
Calorific value, calorimetric, Kg./cal.	10,770
,, ,, effective ,, ...	10,050

The Engler distillation gave:—

Fraction b.p.	Up to 110°	110°-120°	120-°130°	130°-140°	140°-150°	Total
Volume in c.c.	3·6	25·5	29·8	21·6	12·1	92·6

The *heavy shale gasoline*, after treatment with diluted sulphuric acid and caustic soda, contained 85·9 per cent. C, 12·45 per cent; H, 1·20 per cent. S and gave an iodine number (Hübl) of 109·7. it possessed the following properties:—

Density d_4^{15}	0·826
,, d_4^{20}	0·8215
Refractive index n_D^{20}	1·4624
Flash point (Abel-Pensky)	3°C.
Viscosity (Engler) at 20°C.	1·00
Calorific value, calorimetric, Kg./cal.	10,700
,, ,, effective ,, ...	10,030

The Engler distillation gave the following results:—

Fraction b.p.	Up to 160°	160°-170°	170°-180°	180°-190°	190°-200°	Total
Volume in c.c.	1·9	29·6	32·8	18·0	9·5	91·8

The *shale gas oil*, after a light refining with 5 per cent. of 90 per cent. sulphuric acid (loss 5·7 per cent.) followed by 10 per cent. of 10 per cent. caustic soda and redistillation at 175°C. in a current of superheated steam, contained 86·5 per cent. C, 10·96 per cent. H and 1·43 per cent. S, had an iodine number (Hübl) of 84·25 and possessed the following characteristics:—

Density d_4^{15}	0·900
,, d_4^{20}	0·8965
Refractive index n_D^{20}	1·5075
Flash point (Pensky-Martin)	69°C.
Viscosity (Engler) at 20° C....	1·20
Calorific value, calorimetric, Kg./cal.	10,470
,, ,, effective ,, ...	9,880

The Engler distillation gave the following results:—

Fraction b.p.	Up to 200°	200°-225°	225°-250°	250°-275°	Total
Volume in c.c.	0·8	11·6	32·3	28·2	72·9

Shale lubricating oils: The high boiling fractions were refined by treatment first with 90 per cent. and then with 98 per cent. sulphuric acid followed by caustic potash (10 per cent.) and distillation first with superheated steam and then in a vacuum. Representative fractions, obtained in this way, possessed the following characteristics:—

Pressure	13 mm.	13 mm.	13 mm.	1·0 mm.
Boiling range	170°-190°	190°-210°	210°-230°	ca. 180°-230°
Carbon (per cent.)... ...	87·2	87·25	86·8	86·3
Hydrogen (per cent.) ...	10·7	10·8	10·7	9·7
Sulphur (per cent.) ...	1·62	1·71	1·83	2·44
Iodine number (Hübl) ...	46·3	48·4	52·5	59·1
Density, d_4^{15}	0·952	0·9671	0·984	1·007
,, d_4^{20}	0·949	0·9635	0·982	1·002
Refractive index n_D^{20} ...	1·541	1·550	1·560	1·575
Flash point (Pensky-Marten) °C.	145	159	172	198
Viscosity (Engler) at 20°C.	2·12	4·25	11 0	—
,, ,, at 50°C.	—	1·67	2·43	11·6
,, ,, at 90°C.	—	—	—	2·05

Traces only of solid hydrocarbons were obtained when corresponding preparations obtained in the same way from shale oil of different origin were examined for paraffin wax.

A product intended for use as *furnace fuel oil* and prepared by topping 7 per cent. of crude gasoline from the crude shale oil by means of steam, contained 86·1 per cent. C, 9·7 per cent. H and 2·5 S, and possessed the following characteristics:—

Density d_4^{15}	0·994
,, d_4^{20}	0·991
Flash point (Pensky-Marten)	65°C.
Viscosity (Engler) at 20°C.	10·2
at 50°C.	2·41
Asphalt, insoluble in ether-alcohol (2 : 1)	nil
Calorific value, calorimetric, Kg./cal.	10,130
,, ,, effective ,, ...	9,600

A detailed examination of the acid substances isolated from the crude shale oil by means of alkaline solutions showed that they contained phenols, although only very small quantities of the simpler members, such as cresols and xylenols, were present.

The basic substances extracted by means of diluted sulphuric acid were also found to be mainly high boiling. The lower boiling fractions, ranging in boiling point from 135° at normal pressure to 150° at 12 mm., were found to consist almost entirely of substances belonging to the pyridine series, from picoline upwards.

THE PRACTICAL USE OF THE SHALE OIL

It has been found, when refining the corresponding fractions of different crude oils, that products obtained are very similar to each other, and that the difference in the cost of refining oils of different quality does not correspond with the decrease in the output of crude product which occurs as a result of precautions (such as a careful heat treating of the shale) intended to improve the quality. Experience has, in fact, shown that the highest yield of crude oil possible should be aimed at during the destructive distillation. As this requirement was best fulfilled by the above-mentioned plant at Kinne-Kleva, the products obtained from it were used in the final investigation to determine which commercial products could best be produced from the Swedish oil.

In theory it is possible, of course, to produce from the crude shale oil fuel oils of any degree of volatility, but if these are to be of any practical use it is essential, on account of their sulphur and unsaturated hydrocarbon content, to subject them to a more or less drastic refining treatment. It is, therefore, of considerable importance to know to what extent this refining must be carried for different purposes, and also to know the most suitable way of doing it. Experiments were, therefore, made with crude distillates of varying volatility, giving them the lightest safe treatment sufficient for the purposes for which they are intended and then putting them to practical test. The refining agents used were sulphuric acid and potash or caustic soda, followed by redistillation. A few experiments were also made on similar lines with methods in use in the mineral oil industry, such as treatment with floridin, or similar substances, liquid sulphur dioxide (Edeleanu), sodium plumbite solution, aluminum chloride or stannous chloride (Maihle), but the results obtained were not encouraging. Cracking, as was only to be expected, did not offer any advantages for the preparation of the desired products on account of the small amount of hydrogen in the shale oil.

Insufficient of the aviation gasoline was available for test, but it was found that the light gasoline, washed only with dilute sulphuric acid and alkali, could not be used in a Ford automobile motor on account of the carbon deposits formed in the inlet port, on the valves and, to a lesser extent, in the combustion chamber; on the other hand, the same gasoline was found to be quite fit for use after having been subjected to the light refining described above, using 75 per cent. sulphuric acid. The same motor ran on the heavy gasoline and consumed 13 litres in 2 hours without giving trouble. The lightly

refined gas oil, as well as the topped crude oil, when used in Atlas and Diesel motors of the ordinary construction gave trouble on account of incomplete combustion. The latter oil proved quite suitable for its real purpose, *i.e.*, as furnace fuel oil.

The lubricating oils prepared from the high boiling shale oil fractions although good lubricants, could not be compared with imported mineral lubricating oils, both on account of their tendency to resinify and form pitch and then decrease in viscosity with rising temperature. They were, however, considerably superior to the substitutes produced in Sweden during the war.

ZUSAMMENFASSUNG

Schweden ist reich an bitumenhaltigen Schiefern, die während mehr als 200 Jahren zur Bereitung von Alaun benutzt wurden. Sie werden direkt als Brennstoff gebraucht, besonders zum Brennen von Kalk in Gegenden, wo sie zusammen mit Kalkstein vorkommen. In den letzten 50 Jahren haben die bitumenhaltigen Bestandteile des Alaunschiefers auch ein gewisses Interesse erweckt für die Herstellung von Ölen, und in den letzten Jahren wurden eine Anzahl kleinerer Anlagen zu diesem Zwecke gebaut.

Die Möglichkeit, Schwefel, Kalisalze usw. herzustellen, wurde im Jahre 1913 von einer Königlichen Kommission untersucht. Seit dem Kriege wird diese Arbeit vom schwedischen Institut für wissenschaftliche und industrielle Forschung teils durch Laboratoriumsversuche, teils durch Untersuchung der verschiedenen, für die beste Verwendung der Schiefer vorgeschlagenen Verfahren, fortgesetzt. Die Laboratoriumsarbeiten wurden grösstenteils unter der Leitung des Verfassers ausgeführt, und hierüber wird in vorliegender Schrift in aller Kürze berichtet.

Nach einer Übersicht über die Menge und Elementarzusammensetzung der organischen Bestandteile des Schiefers wird das Verhalten dieser Stoffe beim Erhitzen und gegen chemische Reagentien geschildert, und die Zusammensetzung, die chemisch-technischen Eigenschaften und die praktische Verwendbarkeit der bei der trockenen Destillation des Schiefers entstehenden Öle beschrieben.

RECENT ADVANCES IN CRACKING

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS

DR. A. E. DUNSTAN AND R. PITKETHLY

Paper No. F8

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GENERAL—LIQUID-PHASE PROCESSES (*a*) CROSS PROCESS; (*b*) DUBBS PROCESS; (*c*) HOLMES-MANLEY PROCESS; (*d*) JENKINS PROCESS; (*e*) OTHER PROCESSES—VAPOUR-PHASE PROCESSES (*a*) GYRO PROCESS; (*b*) KNOX PROCESS; (*c*) LEAMON PROCESS—ZUSAMMENFASSUNG

A REVIEW OF CRACKING

Within the last ten years cracking has become one of the most important processes of the petroleum industry, and only those who have been intimately connected with it can realise how much work and effort have been expended towards the perfecting of processes. Without doubt the greatest advance that has been made within the petroleum industry during recent years is the development of the modern cracking plant. This development has been made almost entirely in the United States of America, notwithstanding the fact that inventors in most European countries as well as in America have filed innumerable patents for the production of motor spirit from heavy or less valuable oils. The Dubbs process alone claims about 1,200 issued or pending patent applications.

Various factors made the development of cracking processes possible in the United States, one of the most important being the possibility of marketing a high end point gasolene. Normally, cracked oil is deficient in low boiling fractions and yields about twice as much Navy end point spirit as British No. 1 quality petrol. Of the number of processes which have been invented only a few have advanced beyond the experimental stage, and these have either had special facilities for development or unusually sound features in their design.

Vapour phase cracking processes were first in the field.[1] These processes worked at high temperatures and with little or no pressure, but they produced a spirit which was most difficult to refine and had various objectionable features such as high gumming propensities, bad colour and disagreeable odour. It was dissimilar from straight-run spirit in chemical composition.

Attention was thus turned towards cracking at lower temperatures, under which conditions products of a less unsaturated character are obtained. As a result liquid-phase processes were developed.[2]

Liquid-phase processes now operating are responsible for the manufacture of the immense quantity of gasolene which is obtained from heavy products to-day. During 1927 this production amounted to over 100 million barrels in the United States.[3] Compared with this figure the quantity of cracked spirit manufactured in other countries is almost negligible. The amount of coke made in the modern cracking plant is only a small percentage of the throughput but the production of over a million tons of this material in 1927 is an indication of the proportions to which cracking has developed.

Within the last three years there has been more interest in cracking outside the United States, and cracking plants, mostly of the Cross and Dubbs type, have been erected in several countries.

In England, Canada, India, Australia, Trinidad, Borneo, Java, Japan, Roumania and Curacao there are thirty units of the Dubbs process either in operation or under construction. The Cross process has twenty-one units in operation in Argentine, Canada, Curacao, England, India, Japan and Poland, and the Jenkins process is in use in Japan and Canada.

By the use of cracking, the rapid development of motor transport has been made possible, and it has been the most effective step that has yet been made towards the conservation of petroleum resources, for without cracking the increase in the demand for motor fuel would have resulted in a great depletion of underground supplies of crude oil with over-production of heavy residues.

The history of the development of liquid phase or semi-liquid phase processes which have become commercial propositions has yet to be written. Many troubles and great difficulties were encountered and overcome before the efficient and easily controllable modern cracking unit became possible. These difficulties were almost entirely of an engineering character, as the conditions of temperature and pressure used in liquid-phase cracking are such that it became necessary to develop a new technique in order to meet the new conditions. Ten years ago no engineer would

have undertaken to produce a present-day Cross reaction vessel, neither was he in the position to guarantee it to stand up to working conditions.

Naturally the technology of cracking proceeded in advance of engineering. Operators became accustomed to the idea of handling and controlling streams of oil at high temperature and pressure, but they were greatly handicapped in the early stages of development by the lack of materials suitable to withstand the conditions of liquid-phase cracking, absence of efficient measuring and controlling instruments, the inability to pump hot oil and the unavoidable waste of fuel in furnaces of crude design. The development of cracking plant has more or less been concerned with the solution of these and other difficulties, minor details perhaps, but some of them of great importance in the successful working of the cracking unit; even the making of a joint which would remain oil-tight under high temperatures and pressures was a problem of some difficulty.

These problems, however, have been overcome satisfactorily. Pyrometry has been greatly improved, hot oil pumps have been designed and are in use, furnace construction has advanced and heat transfer improved with a large economy in fuel,[4] automatic control has been developed and chain grate mechanical stokers have come back into use for the purpose of utilising the coke formed. The effect of these improvements has been to increase the capacity of older plants. Thus the flue gas recirculating system has assisted in increasing the capacity of a Jenkins unit by 50 per cent. Recycling of flue gases and air preheating have generally resulted in better yields and greater throughput with economy of fuel and better operating conditions.

Details of construction and operation have been standardised and an immense amount of labour has been expended in the endeavour to perfect each individual process in the race for supremacy. It is noticeable, however, that successful cracking processes have fundamentally the same essentials of simplicity of design and operation. Processes with mechanical scraping apparatus, electrical or catalytic methods, or plant with peculiar devices, have never proceeded far beyond the laboratory or the patent office. Refiners with their previous experience of comparatively simple refinery plant have invariably avoided unusual accessories.

The principal modern liquid-phase processes rely on heat treatment only to effect cracking, hence the majority use a cracking coil and a reaction chamber or chambers. The heat necessary for cracking is imparted to the oil in the cracking coil and the time for

completion of the reaction is obtained in the reaction vessel. The reaction vessel is not usually heated, or is supplied with enough heat only to balance the loss due to radiation. It also provides a convenient receptacle for any coke formed in the process. The difference between the various processes lies mainly in the design of the reaction vessels and the method of operation, *i.e.*, the quantity of heat applied and the pressure used. The design and operation determine to some extent the purpose for which the plant is most suitable. For example, a plant such as the Dubbs is *more* suitable for the cracking of heavy crude oil distillates and residues than the Cross type of plant, which preferably uses gas oil and kerosene as cracking stock, because the Dubbs reaction vessel is particularly designed to hold a large quantity of coke, such as may be expected from heavy residues, and the working pressure is comparatively low, whilst the Cross reaction vessel is restricted in its capacity for coke and the working pressure is necessarily high for the purpose of maintaining light distillates substantially in the liquid phase. The flexibility of processes, however, has greatly increased within the last few years and almost any kind of raw oil can be treated to yield marketable gasolene.

When vapour-phase cracking was abandoned in favour of liquid-phase processes no data was available regarding the physical conditions of the oil under treatment at high temperature and pressure, and much experimental work has been done to obtain data applicable to liquid-phase cracking.[5] The results of this work show that temperature, pressure and time all have their effects.

The formation of carbon in the process of cracking was one of the problems of greatest interest because the continuity of the process depended on the extent of its deposition in tubes or stills. The object of most of the patents taken out was to produce the maximum amount of gasolene with the minimum amount of coke. The general experience was that the higher the temperature used the greater the amount of carbon formed. It was established that within the usual cracking range of temperature there is a definite time-temperature relationship. Within this range of temperature the yield of spirit is a function of the temperature if the time is constant. Thus with a typical gas oil the gasolene yield is doubled for approximately each 10°C. rise in temperature. At constant temperature the yield, in the early stages, is a function of the time, following a relationship at first linear but ceasing to do so after material decomposition has proceeded.

The maintenance of a true liquid phase is also dependent on the

time and temperature factors because at constant pressure the liquid phase merges into vapour phase as the critical temperature falls, due to increase in the proportion of cracked products. There is an optimum yield of cracked gasolene obtainable for a given pressure. If the cracked product exceeds this optimum then distillation proceeds at an excessive rate and concentration of the heavier portions of the oil results in a rapid deposition of coke. With a higher pressure the critical yield point rises correspondingly. As an example a particular gas oil at 400 lb. pressure gave a critical yield of approximately 20 per cent., at 700 lb. 25 per cent. and at 1,000 lb. 30 per cent., the temperature of cracking being adjusted, but other conditions remaining constant in all cases.

The velocity of cracking depends not only on the time and temperature but also on the character of the original oil. Kerosene requires a longer time or a higher temperature than gas oil to yield the same quantity of gasolene.

It is probable that paraffins do not form condensation products on cracking and that the coke usually obtained in cracking is mainly produced from aromatic or other ring compounds. Heavy petroleum with a high aromatic content yields large quantities of coke, whereas paraffin wax yields little or none. Increase of pressure tends to diminish the content of unsaturated compounds in the cracked product.

More interest in vapour-phase cracking has become apparent since the work of Ricardo[6] on engine design and Midgley on anti-detonators has become generally appreciated.[7] The use of lead tetraethyl for doping straight run gasolene to prevent pinking was responsible for a search for other substances of similar value. Up to date, no material has been found which is more generally used than benzol for this purpose. Benzol in itself is a fuel, besides having the property of preventing pinking. The extensive use of benzol has in its turn created a demand for a substitute and vapour-phase cracked gasolene appears to meet all requirements.

It is commonly claimed that cracked gasolene is superior to straight-run gasolene in anti-knock value, but this claim depends on the type of crude oil used for cracking and also on the process by which it is cracked. In liquid-phase processes, the gasolene produced from certain crude oil residues or distillates is little better than the straight-run gasolene from the same crude oil. In vapour-phase cracking, however, the original oil is profoundly changed and yields a product which is totally different in chemical composition and is superior in anti-pinking properties.

These facts are particularly noticeable with paraffin-base crude oils. The straight-run gasolene has comparatively little anti-knock value and, if the residual oil after removal of the gasolene is cracked under moderate pressure, the cracked gasolene obtained is similar to the straight-run product. If, however, the residual oil is cracked in the vapour phase the gasolene obtained has a high anti-knock value and its chemical composition does not resemble either the straight-run or liquid-phase product.

Occasionally, the liquid-phase product is of even less anti-knock value than the straight-run gasolene, this being true of certain shale oils. For the production of a liquid-phase cracked motor fuel of high anti-knock value, it appears that certain crudes must be used as raw material, these being either aromatic or naphthenic in type.

The gases produced in vapour-phase cracking plant may contain 50 per cent. or more of unsaturated compounds, but this figure depends mainly on the temperature used. These unsaturated compounds consisting mainly of ethylene, propylene, butylene and amylene open up a new field for organic synthesis. A certain amount of work has already been done towards the production of special solvents, and it is probable that a great development will take place in the manufacture of synthetic material from the waste gases of the cracking process.

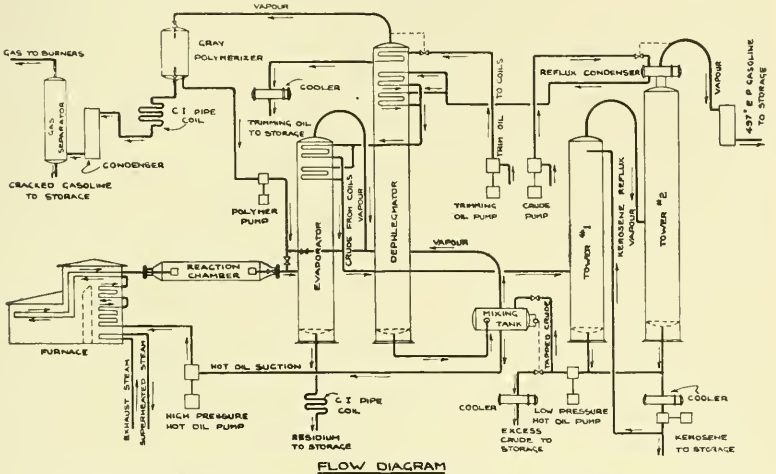
PRESSURE DISTILLATION AND LIQUID-PHASE PROCESSES

Burton, sixteen years ago, was the first to produce commercial quantities of gasolene, and large quantities of gasolene are still being manufactured in various modifications of his original plant. The danger due to deposition of carbon on the bottom of heated shell stills and the recognition of the fact that there is a time lag between the application of heat and the completion of the cracking reaction led to the modern practice of separating the heating section of the plant from the reaction section. Heating is conducted in tube stills which are safer and more efficient than shell stills and the reaction vessel is either lagged or is provided with sufficient heat only to prevent radiation losses.

Of all the liquid-phase or semi-liquid phase cracking processes, the Cross, Dubbs, Holmes-Manley, Jenkins, and Tube and Tank are the principal processes which show continued progress on a commercial basis. A short description of these will show their similarities and differences and indicate the type most suitable for modern conditions.

The Cross Process

The Cross process differs from other commercial processes in that it more nearly approaches true liquid-phase cracking on account of the comparatively high pressure (600 to 850 lb. per sq. in.) under which the process is conducted. The capacity of Cross units now operating and under construction amounts to over 25,000,000 barrels of gasolene per annum. There are at least 175 units now in use. A modern Cross unit is illustrated in Fig. 1.



FLOW DIAGRAM

CROSS CRACKING UNIT WITH GRAY POLYMERIZER AND CRUDE FRACTIONATING TOWERS

Fig. 1.

During the last few years improvements in the plant include reduction of fuel above the fixed gas consumed, from over 6 per cent. to 0·5 per cent. The "synthetic crude" unit with no distillation apparatus has been changed to units equipped with towers for producing a pressure distillate and later the pressure distillate towers have been replaced by bubble-cap towers yielding end point gasolene, with fractionation so complete that there is no overlap between the end point of the gasolene and the initial point of the reflux. Fresh crude capacity has increased to 2,000 barrels per day with a corresponding increase in the daily yield of gasolene. The welded reaction chamber has been replaced by a one-piece forged steel chamber, and the adoption of the Kellogg-Alcorn radiant heat furnace ensures maximum heat transfer with better control over the heat input.

In the modern plant the charging stock is fed by cold oil charging pumps through heat exchange coils in the top of the fractionating

tower and evaporator and is discharged into an accumulator tank. Vapours from this accumulator tank pass into the fractionating tower. The bottoms from the accumulator tank are taken by hot oil pumps to the cracking furnace at a pressure of 600 to 850 lb. per sq. in., and discharged from the cracking furnace into the reaction chamber at a temperature varying from 450°C. to 480°C. The synthetic crude leaves the reaction chamber through a piston type slide valve, at which point practically all the pressure is released. The synthetic crude discharges into the vaporiser where the heavy ends are withdrawn as fuel oil, the vapours passing from the evaporator into the fractionating tower, from which any end point gasolene desired is taken off overhead. The bottoms from this bubble tower are withdrawn hot and charged continuously into the accumulator tank, whence they are passed to the heating coil. Through temperature control, any end point gasolene desired can be made direct from the unit and any quality of fuel oil desired can be withdrawn from the bottom of the evaporator.

In this operation practically no vaporisation is allowed to occur in the cracking zone.

The oil is maintained in a substantially liquid phase, not only in the period in which it is brought to cracking temperature, but also during and until the completion of the cracking reaction in the chamber.

While it is stated that the Cross process is a liquid-phase process this should not be interpreted as meaning that there is no gas in the reaction chamber. A certain amount of fixed or non-condensable gas is, of course, formed. The higher the pressure maintained, the smaller the amount of gas formed and the lower the losses.

The coke made in the Cross process varies from 2·5 lb. per barrel of fresh stock charged in the case of Smackover topped crude to less than 0·1 lb. per barrel when cracking kerosene.

The average yields from the Cross process based on fresh stock charged are:—

	CRACKING STOCK		
	Kerosene. per cent.	Gas Oil. per cent.	Fuel Oil. per cent.
Gasolene 437°F. E.P. ...	78 — 80	65 — 70	45 — 55
Fuel Oil	15 — 20	20 — 25	37 — 55
Coke, gas and loss ...	9	9	8

The percentage of time that Cross units are on stream when operated normally, is about 93 per cent. with kerosene, 90 per cent. with gas oil, and 85 per cent. with fuel oil charging stocks. The length of time on stream depends on the degree of cracking; the

harder the cracking, the greater the loss and the shorter the period of time on stream.

THE DUBBS CRACKING PROCESS

During the last three years many improvements have been made in operation and lay-out of the Dubbs plant. Three to four years ago a standard Dubbs unit had a fifty tube 4-in. heating coil from which the cracked oil was discharged into a 10 ft. by 15 ft. reaction vessel, whereas a modern unit may have up to 2,500 barrels capacity, and may contain a heating tube furnace equipped with 136 5-in. tubes. The reaction chamber has increased to 10 ft. by 40 ft. high. The dephlegmator has been largely increased with shortening of the reflux leg as hot oil pumps now give a positive feed in place of the uncertain gravity feed of the reflux oil. A flashing chamber and flash condenser may now be added to the outfit, giving still further flexibility to the process. Recycling of the flue gases has resulted in improved operation and, in units having duplicate reaction chambers, the idle time has been largely diminished by running the reaction vessels alternately so that one is in use whilst the other is being cleaned. This method of operation ensures almost continuous running and at the same time provides ample time for de-coking and reconditioning without interfering with the normal working of the process.

There are now over 200 units of the Dubbs process operating on a wide range of raw material in different parts of the world.

The lay-out of a modern Dubbs plant is shown in Fig. 2.

The process is simple in that the oil to be cracked enters a heating coil in the furnace and passes into a reaction chamber in which all the coke produced collects. The fuel oil produced is continuously withdrawn from the reaction chamber, while the generated vapours pass into a dephlegmator wherein the heavier ends are condensed and returned together with the fresh raw oil, to the heating tubes, by means of a hot oil pump. The lighter ends of the cracked vapour pass from the top of the dephlegmator to the condenser. The distillate passes into a receiving tank, from which it is continuously withdrawn to the storage tank.

Only small quantities of oil are within the heating zone of the furnace. The reaction chamber and other parts of the plant are not externally heated and heat losses from these parts of the plant are prevented by heavy insulation. The operating pressures range from 150 to 250 lb. per sq. in.

The length of a run is dependent upon the character of the charging stock which is being cracked. When cracking lighter oils the runs

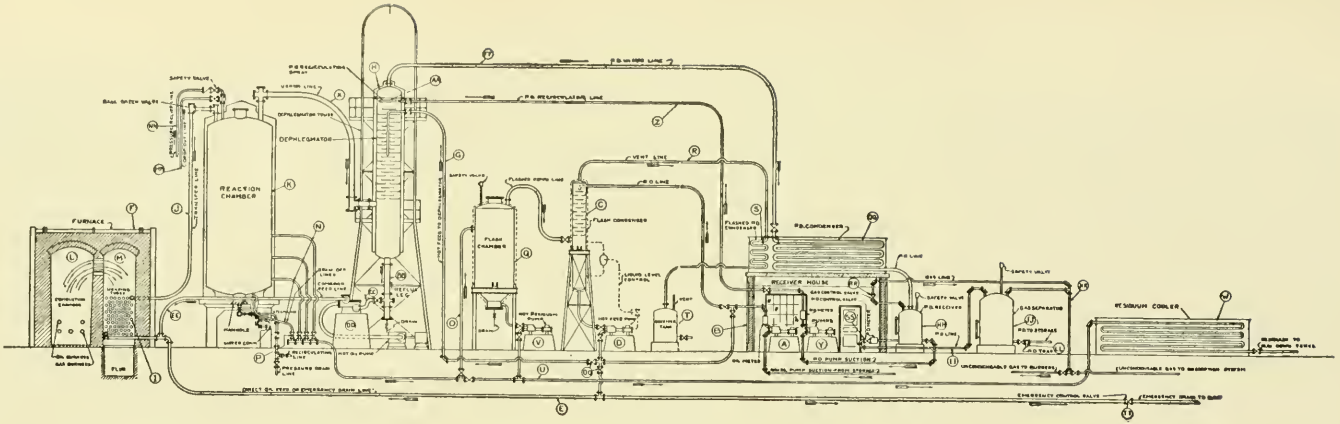


Fig. 2.

The flow chart shows in diagrammatic form the relative arrangement of the equipment comprising the process and the flow of oil and vapour through it.

The charging stock is pumped to the plant at a uniform rate by the feed pump A in receiver house B and fed into the top of the flash condenser C. The ascending vapour in the flash condenser comes in direct contact with the descending charging stock and a portion thereof is condensed, thus preheating the charging stock, which mixes with the condensed vapour. This hot feed is drawn from the flash condenser by hot feed pump D and fed either through the overhead line G to the dephlegmator H, where it is further preheated by ascending vapour, or directly to the heating coil I in furnace F, through the feed line E. Valves OO are provided so that the feed can be split between the dephlegmator and the heating coil.

The oil enters at the bottom of the heating coil I and flows through the tubes which are connected by return fittings to form a continuous coil, being thus heated to the required cracking temperature by the hot combustion gases which flow from combustion chamber L through ports in the dividing wall to the tube compartment M and thence downward between the tubes to the flue and stack. Coil I discharges through the transfer line J into the reaction chamber K, which is heavily insulated but not heated.

The vapour from the reaction chamber passes to the dephlegmator H through vapour line X. The liquid is withdrawn from the lower part of the reaction chamber through draw-off lines N and valves P, being directed through line O to flash chamber Q, where the pressure is reduced.

In the flash chamber the light ends distil off and pass to the flash condenser C, where a substantial portion of said light ends is condensed by the incoming charging stock as heretofore mentioned. The residuum is removed from the bottom of the flash chamber Q by pump V through line U to residuum cooler W and thence to storage. Any uncondensed gas or vapour from the flash condenser C passes through vent line R to a coil condenser S and thence to receiver tank T.

The temperature of the vapour leaving the dephlegmator H is controlled by the amount of cooling accomplished therein. This cooling is mainly effected by the introduction into the dephlegmator of a portion or all of the charging stock or by a more volatile oil, such as a portion of the cracked distillate from the process, which can be fed by pump Y through line Z into spray AA located in the top of the dephlegmator. Normally both charging stock and pressure distillate are used for cooling. A series of perforated pans in the dephlegmator ensures efficient contact of oil and vapours. This cooling causes a refluxing action in the dephlegmator, and the lighter vapour which passes off is separated from the heavier vapour which is condensed and gravitates into reflux leg BB and line CC. The hot oil pump DD then returns this reflux liquid in combination with the charging stock through line EE to the heating tubes I for further cracking.

The light vapour passes from the dephlegmator H through line FF to the condenser GG. The condensed vapour and the uncondensable gas flow from the condenser GG to the pressure distillate receiver HH.

The pressure distillate is discharged from the receiver by control valve SS through line II to the gas separator JJ, where uncondensable gas is released.

The plant pressure is controlled by releasing gas from the receiver through valve RR.

The gas from both the distillate receiver and gas separator may be sent to the furnace burners through line KK or passed to a gasolene absorption system.

The distillate from the gas separator flows through the traps LL to the storage tanks.

The line MM is a drop-out line from the reaction chamber.

The line NN is a pressure relief line from the reaction chamber.

Valve TT in the emergency drain line relieves the pressure from the cracking tubes and drains the hot oil to the sump.

continue uninterruptedly from ten to thirty days, and when a heavy coke-forming oil is being cracked the run lasts from three to five days only.

The products obtained are pressure distillate, residuum or fuel oil, coke and uncondensable gas. The pressure distillate is treated and steam distilled, taking off the gasolene produced by cracking. The bottoms of the pressure distillate constitute a gas oil which may be either sold or mixed with raw charging stock for further cracking. The residuum or fuel oil has the advantage of greater heating value than the original charging stock, as it has a higher calorific value; it also has a lower viscosity and lower cold test. The uncondensable gas may be treated with other refinery gases in an adsorption plant, or may be burned directly under the furnace. The coke is a good commercial grade and has an average market value.

The yields of gasolene obtained from the Dubbs process vary according to the charging stock and the method of operation.

A new method of operation known as the Flashing System, has recently been introduced. This method of operation involves the withdrawal of the residuum from the reaction chamber into an auxiliary chamber, where it is vaporised, or, as is commonly said, "flashed." Thus, the residuum is not permitted to accumulate in the reaction chamber with the resultant large deposition of coke, but is discharged as it forms into the flash chamber at reduced pressure.

The advantages to be gained by this method of operation are:

1. Increased time on stream due to the smaller coke production per barrel of raw oil throughput.
2. A reduction of approximately 80 per cent. of the quantity of coke formed as compared with residuum operation.
3. An improved quality of residuum with low cold test, high flash point and low sediment by benzol test.
4. A reduced liquid loss due to the formation of less coke.
5. A slightly increased gasolene yield and a better quality of pressure distillate.

In the operation of the flash system as applied to a single Dubbs unit, the residuum from the reaction chamber is discharged through a 2-in. line to the 6 ft. by 12 ft. flash chamber. The gas oil vapours released in the flash chamber by the reduction of pressure are carried by a 6-in. line to the 20-in. dia., 20 ft. high, condensing and pre-heating column. This condensing column is equipped at the top with twelve pans similar to those in the dephlegmator. The bottom portion of the column acts as a receiver for the hot feed.

The charging stock from the present raw oil feed pumps is discharged over the top of the pans in the column to condense the gas oil fraction of the flashed vapours. The small amount of the uncondensable gas and light distillate vapours which pass off are condensed by a 120-ft. coil of 2-in. pipe. The condensate accumulates in a small receiver with a vent to release the non-condensable gas.

A Tagliabue liquid level control is used to maintain a constant level in the condensing column by regulating the amount of steam to the hot feed pump. This automatically balances the operation of the unit so that if a large amount of gas oil is flashed off the hot feed pump speeds up and maintains a constant level in the condensing column. This does not tend to increase the load on the cracking plant because the gas oil is returned with its full heat content. It is more in the nature of increasing the reflux ratio to raw oil.

From the bottom of the condensing column the hot feed is pumped either to the dephlegmator or direct to the tubes. An orifice meter is used to indicate the rate of feed to the plant.

From the bottom of the flash chamber the final residuum may be pumped around the fuel oil system, then through a cooler to storage. A portion of it may be returned from the fuel system to the flash chamber in order to lower the gravity of the final residuum by partly cooling the vapours, and to decrease the production of coke.

Non-Residuum Operation. Non-residuum operation differs from the above residuum method in that there is no residuum made, and all the oil charged to the system is converted into pressure distillate as completely as possible. Coke and non-condensable gas are the only by-products, but in larger quantities than in residuum operation.

The Holmes-Manley Cracking Process

The Holmes-Manley apparatus generally employed comprises: a pre-heater coil, of the series type, in which the oil is raised to a full cracking temperature; four vertical stills, or reaction drums (5·6 ft. by 40 ft.), into which the oil discharges; a bubble tower type of dephlegmator which receives the vapour from the stills; a reflux condenser, to which the vapours pass from the top of the bubble tower; a water-cooled condenser, which receives vapours from the reflux condenser; a surge pump, which returns the clean, heavy condensate from the bottom of the bubble tower and forces it into the stills through the pre-heating coil along with raw oil; and expansion drums into which the residue from the stills is drawn and distilled

by the contained heat giving recycle stock. A condenser coil condenses the vapours from the expansion drums. The oil traverses the heating coil so rapidly that while it is being heated to full cracking temperature—approximately 425°C.—no substantial decomposition occurs in the coil, and carbon deposition is avoided.

Oil is maintained at an approximately even level in the vertical stills, which are set in a furnace with the ends projecting above and below the furnace.

Scrapers are mounted on vertical shafts in each still and are rotated slowly during the operation, thus preventing the accumulation of

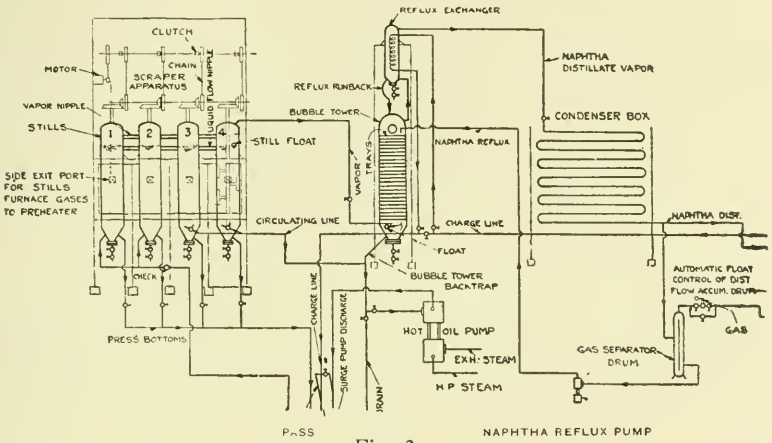


Fig. 3.

carbon on the heated surfaces. Any carbon formed tends to gravitate to the cooler bottom space, below the heated zone.

The oil in the stills is equalised by liquid inter-connections just above the furnace at the point where it is desired to maintain the oil level, the vapour being taken off the stills as fast as formed and led directly to the bubble tower.

A comparatively low furnace temperature is maintained around the stills, in fact, sufficient only to compensate for loss due to radiation as most of the heat is supplied to the oil in the coil. The oil is maintained in the stills at a slightly lower temperature than at the exit of the coil, cracking being carried on in the stills at a relatively low temperature, approximately 415°C. A comparatively long time element is obtained and a better and more complete conversion effected by the use of four stills instead of one. The working pressure may be from 150 to 600 lb. per sq. in., according to the construction.

"Clean circulation" is obtained by the return of the hot reflux from the bottom of the bubble tower to the pre-heating coil, none of the undistilled residue being permitted to return to the coil.

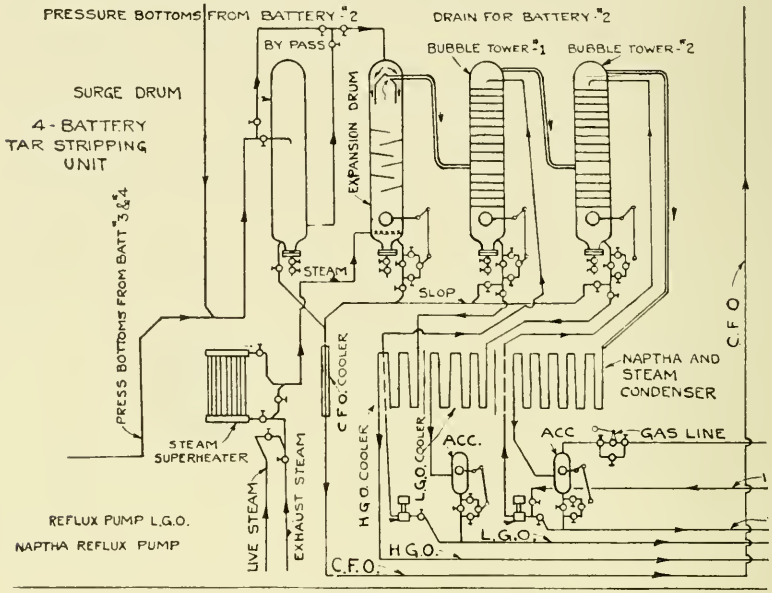


Fig. 4.

The result of the Holmes-Manley operation is to produce gasolene directly from the pressure stills without re-running, as the bubble tower is operated under pressure. The residue from the expansion drums is a high gravity, merchantable liquid fuel, and the total carbon and fixed gases produced in the system is small.

As far as is known the Holmes-Manley plant holds the record for continuity of working without a forced shut-down owing to coking.

Operating in mid-Continental gas oil the following figures illustrate the performance of the plant.

Operating time as percentage of calendar time	90
Mixed charge per 24-hour operative day, 42 gallon barrels ...	2,500
Percentage of virgin gas oil in charge	56
Percentage of cycle gas oil in charge	44
Naphtha Dist. of 230°C. E.P. made by unit, including tar stripper per 24-hour day, barrels	1,000
Gasolene of 205°C. E.P. produced per 24-hour active day by re-running of naphtha distillate, barrels	850
Furnace oil	112
Fuel oil of furol viscosity at 122°F.	325
Gas	105
Coke and loss	8

The Jenkins Cracking Plant

The Jenkins process[8] was first applied commercially about four years ago; it now has units in operation in most of the important refining centres. It is being operated with crude oil, topped crude gas oil and fuel oil residuum as charging stock. Details in construction vary with different installations, and the following description will be confined to the general phases of operation covering the essential features common to all installations.

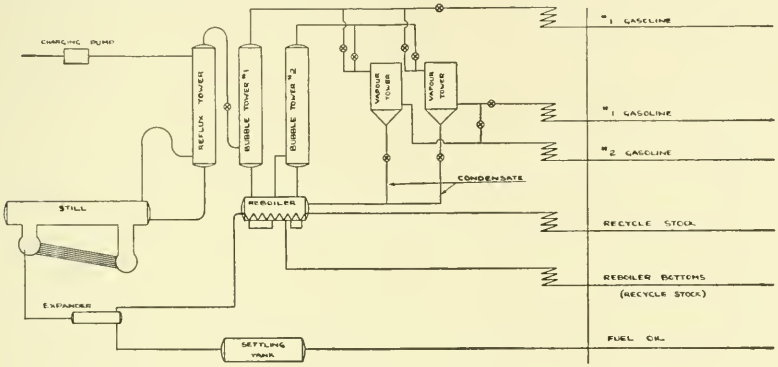


Fig. 5.

Flow Chart. Jenkins Installation in which Gasolene is treated in Vapour Phase.

The charging stock from storage enters the unit through a reflux tower, where it comes in contact with the vapours direct from the cracking still. This contact of liquid and vapour serves to preheat the former, vaporising the light ends, should any be present, and, at the same time, recondenses all the heavy ends in the vapour. The liquid charge as reflux from the base of this tower flows down to the cracking still, which consists of a horizontal shell still with a capacity of from 8,000 to 10,000 gallons. Underneath this shell and near both ends are sluiceways or legs connecting to cross drums. The front leg is shorter than the rear leg, so that the numerous tubes which connect the two cross drums slant down from the front to the rear. These tubes, 120 or more, are exposed to the heat of the furnace. Near the upper part of the rear leg is a propeller which determines the rate of oil circulation in the still. This propeller is driven at a constant speed by a 35 H.P. electric motor located on top of the still.

This arrangement for oil circulation in the still is one of the unique and basic features of the Jenkins process. The propeller device ensures the complete circulation of the oil in the still approximately

once every twenty seconds. The rapid circulation of the charging stock with the vapours constantly passing off to the fractionating towers tends to prevent "over cracking" and reduces the amount of carbon deposited in the still.

As the charging stock is being pumped to the cracking unit a small amount of hydrated lime is fed into the line. The amount of lime used varies with the charging stocks but generally does not exceed 50 lb. of lime per 100 barrels of charging stock. Owing to the lime, the small quantity of carbon produced is in the amorphous form, and most of it settles out of the fuel oil residuum from the cracking operation in the fuel oil settling tank.

The use of lime in the charging stock also tends to lessen the treating problem for the finished products, and adds to the life of the equipment by reducing corrosion in the still and towers.

A predetermined amount of the charging stock is drawn off continuously from the front cross drum of the cracking still. This liquid contains a considerable quantity of light ends which are allowed to vaporise in the expansion chamber and pass to the "reboiler." The residual liquid, which contains a small quantity of coke in the amorphous form, as previously explained, goes to a fuel oil settling tank, where the carbon settles out. The liquid residuum is a fuel oil of very high grade specification, and possesses a low cold test.

The cracked vapours, freed from the heavy ends which have been absorbed by the incoming charge in the reflux tower, pass to a large bubble tower, near the base of which the reflux is removed and dropped back into the shell of the reboiler. Here the light ends of the reflux are again vaporised by the hot vapours in the coil from the expansion chamber, the vapours from this heat exchange operation being returned to the bubble tower for further fractionation. The heavy ends as reboiler bottoms pass to cooling coils. Both these reboiler bottoms and the recycle gas oil can be blended with fresh stock and utilised as charging material for the cracking operation. In many installations, the recycle gas oil constitutes 50 per cent. or more of the original charge.

In regulating the flow of liquid and vapour the control is largely automatic. By means of a temperature control at the top of the reflux tower, the overhead vapour passing to the bubble tower is maintained uniform.

The operating pressures used in the Jenkins cracking operation vary from 135 to 200 lb. per sq. in.

One of the largest users of the Jenkins process charges the bulk

of the raw gas oil charging stock to two units operated at relatively low pressures and temperature. The recycle stock from these units is then charged to a third unit, which is operated at a higher temperature and pressure. In most Jenkins installations it is customary to take both a high and low gravity gasolene stream from the cracking unit, the former often being 75 per cent. of the total gasolene recovered.

As an example of the results obtained with the Jenkins process, a charging stock, consisting of 64·4 per cent. Seminole crude oil, 32·3 per cent. of fuel oil and the remainder gas oil, yielded 65·5 per cent. of gasolene with an end point of 424°F. The loss was 2·91 per cent. The run lasted 612 hours and during this period 18,598 barrels of raw oil were charged to the unit.

With a mixture of 67 per cent. recharging stock and 33 per cent. of Panhandle crude oil, 75 per cent. of cracked gasolene was obtained. Californian gas oil yielded 62·7 per cent. of gasolene and mid-Continent gas oil gave an average yield of 67·66 per cent.

The Tube and Tank Process

In the Tube and Tank process the oil is heated in tubes of small bore, which discharge the oil into reaction chambers. The differences between this plant and the Cross plant are that the reaction chamber is vertical instead of horizontal and that two or more chambers are used. The working pressure is about 250 lb. Connections between furnace and reaction chambers are arranged to allow the mode of operation to be varied. Thus they may be used singly, in parallel or in series, while it has been found that with two reaction chambers the process has great flexibility in meeting varying conditions. If used separately, one reaction drum may be cleaned whilst the other is in operation.

As in the Cross process, pressure is released as the oil leaves the reaction chamber and evaporation proceeds immediately in the separator tank. The oil reaches this tank at about 400°C., which is high enough for vaporisation without the application of additional heat. The separators are connected to fractionating towers which condense the heavy fractions but allow the gasolene fraction to distil. It is claimed that the process permits the handling of a larger amount of charging stock per day than many of the other processes in use to-day.

Other Processes of Interest

The only process depending on the use of a catalyst is the McAfee process, in which aluminium chloride is used. The process has

many points in its favour, the use of pressure being unnecessary. and it is carried out at a comparatively low temperature. The cost and the recovery of the catalyst have, however, hindered its development.

The Blümner process[10], which has been developed recently in Germany, differs from the usual process in the manner in which the heat is applied. The oil to be cracked is injected at a pressure of about 600 lb. per sq. in. into a chamber containing molten lead. Raschig rings are immersed in the molten metal in order to prolong the passage of the oil to the surface. The advantages claimed for the method of heating are:—

(*a*) very rapid raising of the temperature to the cracking stage while

(*b*) subjecting every particle of the oil to the same conditions of temperature and pressure,

(*c*) avoidance of local overheating and

(*d*) continuous operation, as very little carbon is deposited.

In this process the cracking stock is forced through a heat exchanger and mixed with hot reflux oil, then pumped through a preheater coil heated by the flue gases from the autoclave furnace. The oil leaves at a temperature up to 300°C. and is forced under pressure into the autoclaves containing the molten lead, where it reaches a temperature of 450°C., thence passing into well-insulated decomposing chambers, where the reaction is completed. The cracked oil passes through an automatic relief valve into a spraying vessel, which is maintained at a temperature of 300°C. by gas firing. Heavy oil or pitch is deposited and removed from the system, while the light fractions flow to an air cooler which condenses the reflux oil for recycling to the heat exchanger. The vapours pass through a column, condenser and a water separator to the gasolene receiver. The gas made in the process is utilised to heat the autoclaves.

The Bergius process[11] is the only process working under an extremely high pressure which has developed to a commercial scale. Little information as to progress has been obtainable lately regarding the cracking of oil, but it is probable that the plant has not changed fundamentally.

The usual methods of cracking oil produce gas and coke, the latter being a great hindrance to the continuous method of working. Bergius took up the problem and by applying heat in the presence of hydrogen under great pressure found that practically no coke and very little gas were formed when he cracked heavy oils at a temperature of about 450°C. and 100 atmospheres initial pressure.

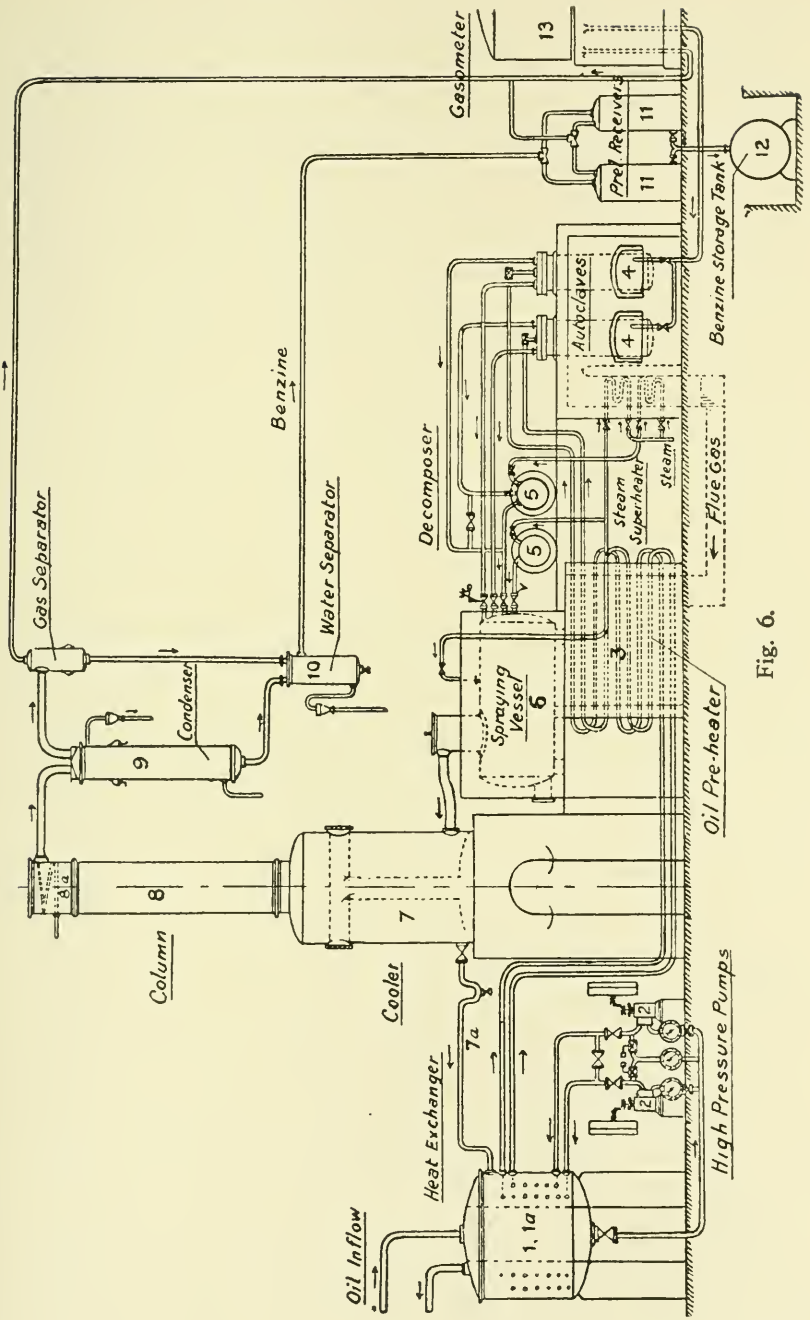

Gasometer
13
Pre-Reservoirs
11
12
Benzine Storage Tank
Autoclaves
4
Benzine
Decomposer
Steam Superheater
Steam
Flue Gas
Gas Separator
Water Separator
10
Condenser
9
Spraying Vessel
6
3
5
Oil Pre-heater
8
8a
Column
7
Cooler
7a
Heat Exchanger
2
High Pressure Pumps
1, 1a
Oil Inflow

Fig. 6.

The commercial unit consists of a heavy horizontal steel cylinder. Inside the cylinder there is a cast-iron vessel, 30 ft. long and 3 ft. diameter, placed on concrete slabs sloping towards the closed end. It is fitted inside with a stirring device which penetrates to the far end. The heating is effected by passing nitrogen through coils heated in a furnace, then through the annular space between inner chamber and the heavy steel wall of the autoclave.

Oil and hydrogen are preheated and sprayed into the autoclave continuously and the light products are removed as rapidly as they are formed, the high boiling fractions dropping back for further hydrogenation. The heavy residue is continuously withdrawn from the bottom of the vessel.

The plant can deal with 50 tons per day and as no carbonisation occurs, continuous working for an indefinite period is practicable.

The final pressure reached is sometimes as high as 280 atmospheres.

The colour of the Berginised oil is red or yellow, whereas cracked oil is opaque and very dark in colour.

The hydrogen consumption is about 1 per cent. and the gasolene after refining with less than 1 per cent. of acid and soda is water white. The kerosene is barely coloured and both have a pleasant odour. Fuel consumption is about 6·5 per cent. and the gas produced contains enough latent hydrogen for the Berginisation of the oil.

A fuel oil, S.G. ·986, passed once through the plant yielded 84 per cent. of distillate, 8 per cent. of gas, and left a residue of 8 per cent. The distillate contained 30 per cent. gasolene, 25 per cent. kerosene and 37 per cent. gas oil and heavy oil, the losses due to gas, etc., being 8 per cent.

VAPOUR PHASE CRACKING[12]

The situation regarding vapour-phase processes is somewhat difficult to analyse on account of the lack of data on yields and cost of production. It is generally known that vapour-phase cracking shows a much higher loss in the form of gas and that the yield of spirit is less than by liquid-phase cracking, but these facts must be considered as well as the properties of the product and the advantages claimed for the particular process which usually accompany any published information on the subject of vapour-phase cracking.

The principal difference between liquid-phase and vapour-phase cracking is the temperature at which the process is carried out. In liquid-phase cracking, the temperature of operation may range

between 380° and 480°C., whereas in vapour-phase a minimum temperature of about 600°C. is necessary.

The long time factor characteristic of the liquid-phase process is absent in the vapour-phase process, as the reaction at this high temperature is extremely rapid. The high temperature, however, is more likely to cause deterioration of the heating coils, but large reaction vessels such as those employed in the liquid-phase process are unnecessary. No high pressures are used in vapour-phase processes. The products obtained from the same oil in vapour-phase are totally different in composition from the liquid-phase products. Practically no coke is formed.

It is unlikely that vapour cracking will ever supplant the liquid-phase process, but many oil companies have erected experimental vapour-phase units.

Of the true vapour-phase processes which have been developed from early patents, three of the best known are the Gyro, the Leamon and the Knox.

The Gyro Process

The Gyro process[13] is based on the Ramage patents, which are held by the Pure Oil Company, and the following is a description of the unit at Cabin Creek, W. Virginia. This plant has a capacity of 1,500 barrels fresh charging stock per day. About 95 per cent. of the oil is vaporised for cracking and the process yields about 600 barrels of finished gasolene daily.

The material to be treated is pumped into a pipe-still, each half of which contains 2,800 linear feet of tubing in 30-ft. lengths; heat is supplied by hot gases from the converter supplemented, if necessary, by gas burners. The flue gases are recirculated, 50 per cent. being returned to the converter. The pre-heated oil from the pumps is divided into two streams and enters the tubes from the bottom upwards. From the still the oil passes into an evaporator, where the heavy unvaporised portion is removed as fuel oil and steam is mixed with the vapours. A separator removes any entrained liquid which drains into the bottom of the fractionating tower. After leaving the separator the vapour enters the converter which consists of tubes (10 ft. long, $3\frac{1}{2}$ in. dia.) containing a central core of concrete impregnated with oxide of iron as a catalyst. Each converter has twenty cracking elements of four tubes each, common headers connecting the inlet and outlet ends of the elements. Thus the total travel of the vapour within the converter is 40 ft.

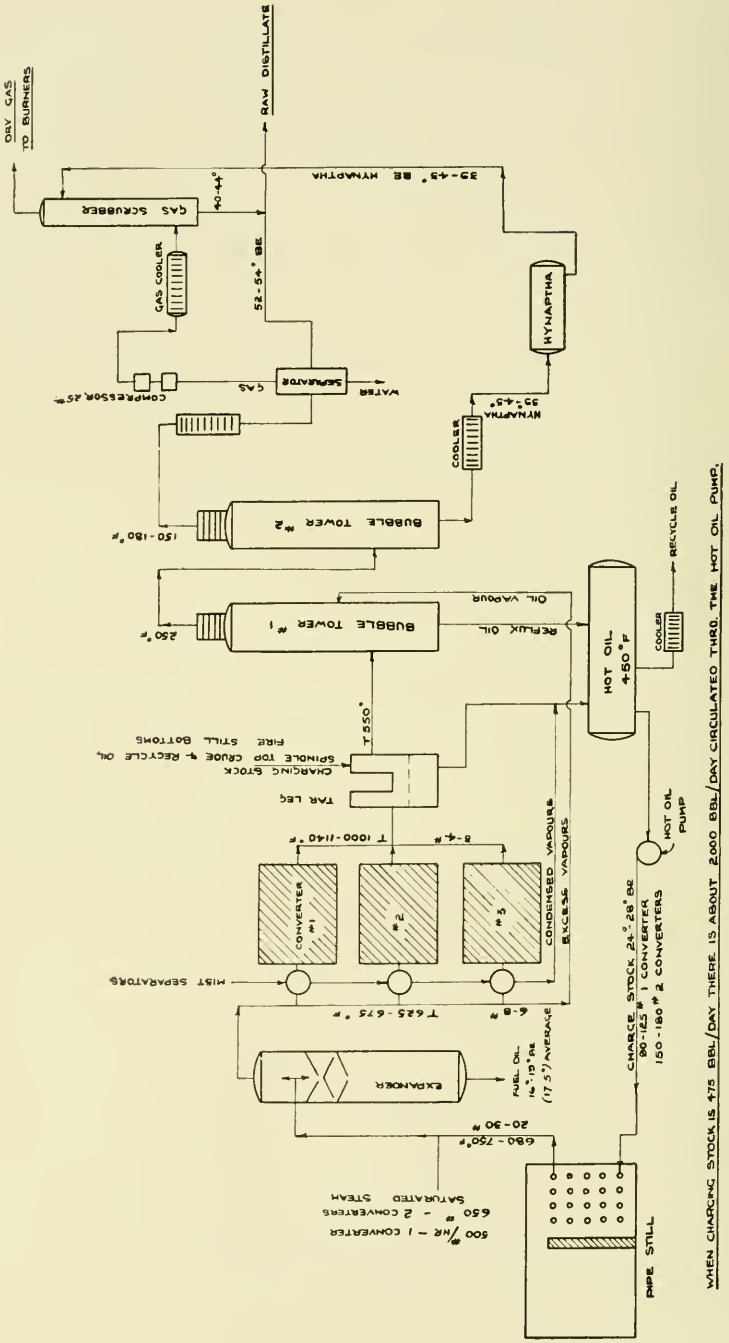


Fig. 7. Flow Sheet for Gyro Process.

Cracking takes place at slightly over 600°C. in the converters and the issuing vapour is conducted into a tar leg which is an important part of the unit. It serves as a jet condenser to cool rapidly the cracked vapour, and consists of a rectangular vessel into the top of which cold charging stock is sprayed. The sudden cooling reduces the formation of carbon to a very small quantity, about 1 lb. per 1,000 gallons of gasolene produced. The charging stock is thus preheated and flows by gravity into the bottom of the first fractionating column, mixes with the reflux and thence to the hot oil pump which feeds the pipe-still.

The vapour from the converters enters the first fractionating tower, which is 35 ft. high and 6 ft. dia., and filled with tray baffles; it has a smaller reflux tower, 15 ft. high on top. The reflux tower is designed as a steam generator and more low-pressure steam is made here than is required throughout the plant. At the same time the vapour is cooled to give the required end point spirit.

The fuel heating system of the process is novel. The principal combustion takes place in the converter furnace where waste gases from the process are burned, producing a temperature approximately 1,700°C. Before coming into contact with the cracking tubes, these gases are mixed with gases at about 300°C. The flue gases leaving the converter are still at, roughly, 750°C., and are drawn by a fan through the pipe-still heating chamber; 50 per cent. of the gases circulate back to the converter again, the balance going up the stack and serving in their passage to superheat the steam produced by the fractionating tower.

The fixed gases, amounting to 40 to 60 cu. ft. per gallon of gasolene made, are scrubbed for gasolene recovery before being used as a fuel.

The Knox Process

This process has been developed during the past eight years by the Petroleum Conversion Corporation, which holds the Knox patents. A large scale plant capable of producing 2,000 barrels of gasolene daily is in operation at Texas City.[14]

The special feature of the Knox plant is the method of applying the heat. The gas produced in the cracking of the oil is recirculated in the system after being heated by means of a battery of hot blast stoves. No cracking heat is supplied through metal containers. The charging stock is vaporised in a pipe-still and the necessary heat for cracking is transferred to it while entering the cracking chamber by the gases from the stoves, the temperature of this gas being regulated before entering the cracking chamber.

The fresh charging stock is pumped into the top of a bubble cap fractionating tower and passes together with the reflux to the pipe-still. The vapour from the pipe-still enters the top of the first of a series of cracking chambers and mixes with the hot gases, which are maintained at 600 to 620°C. This rapidly raises the oil vapour to cracking temperature. The cracked gas and vapour leave the last reaction vessel at about 495°C., and pass by way of heat exchangers to the fractionating tower and condensers. The condensate flows to receivers whilst the gas is scrubbed for gasolene recovery. The stripped gas returns through heat exchangers to the hot-blast stoves.

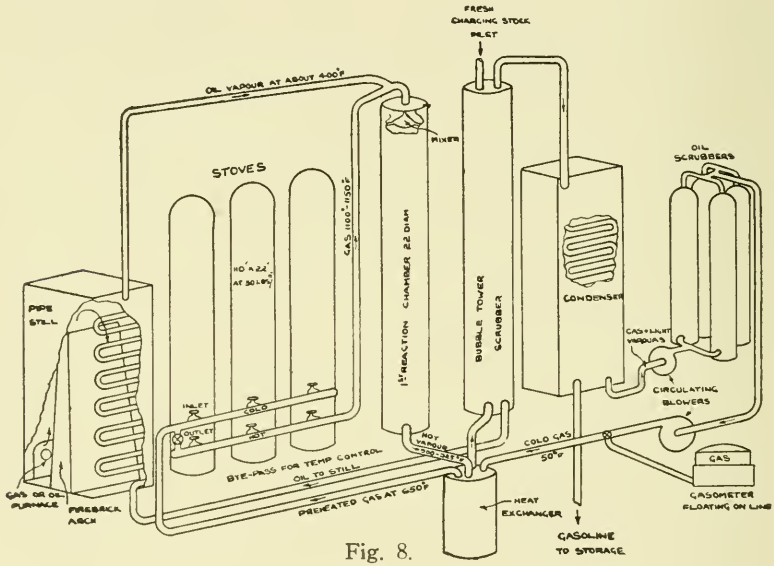


Fig. 8.

The Leamon Process

The Leamon process[15] is one of the few that have been running commercially for some years. The plant consists of a charging tank, into which the reflux oil from the fractionating column returns to mix with raw oil. This mixture is pumped through a heat exchanger to the lower heating coils of a Foster oil heater. From this part of the heater the oil and vapours pass out into a tar drum where the extremely heavy oil, which cannot be vaporised, is condensed and automatically allowed to escape to storage. The vapour returns to the heating element where it is raised to as high a temperature as possible without carbonising the tubes, and

thence into a catalytic chamber, containing the catalyst, which is claimed to control the composition of the product and reduces the time of reaction. The vapour next passes through a heat exchanger into a fractionating column, thence it is condensed, the reflux returning to the tank feed. The percentage of gasolene in the overhead condensate can be controlled at will, and usually is between 70 and 90 per cent. The gas still uncondensed is freed from mist in a separator, and flows through a venturi tube to a gas recovery plant, where the last remaining fractions of gasolene are recovered.

The stripped gas returns to the furnace to supply heat to the Foster tubes. The differential pressure produced by the passage of the gas through the venturi tube is employed to control the amount of fuel passing to the furnace. By maintaining a constant flow of gas the cracking reaction is maintained at a constant rate regardless of the composition of the cracking stock, and the human element, in determining the correct temperature and maintaining it, has been eliminated.

The yellow naphtha obtained in this way is treated, redistilled and blended with the spirit recovered from the gas.

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ZUSAMMENFASSUNG

Das Cracken ist von solcher Wichtigkeit geworden und die Literatur darüber hat so grosse Ausmasse angenommen, dass es nur möglich war, einen kurzen Umriss davon zu geben.

Es wird versucht, einen Überblick zu geben über den gegenwärtigen Stand des Crackens, über die Entwicklungsursachen der modernen Verfahren, über die Schwierigkeiten, auf die man beim Bau von Anlagen gestossen ist, und über die Erfahrungen, die auf experimentellem Wege aus Anlass der Ausarbeitung der modernen Verfahren gesammelt wurden.

Es wird auf gewisse Verfahren hingewiesen, denen wieder erneut Aufmerksamkeit zugewendet wird und denen eine gewisse Zukunft vorausgesagt wird, sofern es gelingt, sie zur Herstellung von Gegenklopfmitteln und andern als Brennstoff nicht geeigneten Produkten heranzuziehen.

In kurzen Abschnitten über Anlage und Betrieb der hauptsächlichsten heutzutage gebräuchlichen Verfahren wird auf die fundamentale Ähnlichkeit in der Konstruktion hingewiesen, die sich allmählich bei allen Verfahren, allerdings unter Beibehalt gewisser individueller Charakterzüge, ergeben hat.

THE TECHNICAL ASPECTS OF THE STORAGE, HANDLING, AND TRANSMISSION OF LIQUID FUELS BY THE USER

TECHNICAL COMMITTEE, FUEL CONFERENCE, 1928

I. LUBBOCK

*Paper No. F*10

CONTENTS

INTRODUCTION—GRADES OF FUEL OIL—STORAGE—HANDLING—TRANSMISSION—ZUSAMMENFASSUNG

Introduction

It will be noticed from the title of this paper that it concerns matters coming within the scope of the user of fuel oil as commercially marketed. It is not proposed, therefore, to deal with problems of oil companies at their own installations or refineries, except in so far as they have plant similar to that of the ordinary user. An outline is given of the appliances and methods involved, which will follow on the lines of many fluids which have to be handled in industry, and it will be necessary only to emphasise those particular points which differ when a liquid fuel is used, as distinct from water or other fluids.

Grades of Fuel Oil

To appreciate the problems we have to deal with, it is necessary to review the general properties of the different grades of fuel oils which are likely to require handling. It would be entirely beyond the scope of this paper to analyse the numerous specifications in detail, since from the point of view of handling and storage, only a few of the characteristics affect the plant. It is, however, necessary to bear in mind that the word "fuel oil" covers an immense variety of petroleum products, very rarely appreciated by the average user. There is also a great deal of confusion due to loose semi-technical descriptions, such as "light and heavy fuel oil," "residual oil," "furnace oil," and so on.

Whatever further sub-divisions may be applied, it should be explained that as far as this country is concerned, oil fuels are marketed in three distinct commercial categories, *viz.*:—

1. Gas oil. 2. Diesel oil. 3. Fuel oil.

Unfortunately, from the technical point of view each of these names is still open to criticism. All three can be looked upon as "fuel oil;" "gas oil" makes an excellent fuel for a "Diesel" engine; "fuel oil" can be used successfully on certain types of "Diesel" engines; and "Diesel oil" is frequently required for certain types of burners.

At first sight, classification according to gravity would eliminate the above uncertainty. Under this classification the following would generally hold:—

	Specific Gravity	Beaumé
Gas oil ...	... ·84 to ·86 ...	... 36 to 32°
Diesel oil ...	... ·86 to ·90 ...	... 32 to 27°
Fuel oil ...	... ·88 to ·96 ...	... 29 to 16°

However, other characteristics of the oils are found to widen each group until the gravity consideration alone becomes unreliable. For instance, one can have a distillate with a specific gravity of 0·89 having a viscosity of 40 secs. Redwood No. 1 at 100°F. and only 100 secs. at 40°F., as against a residual fuel oil of 0·88 specific gravity having a viscosity of 80 secs. Redwood No. 1 at 100°F. and 13,200 secs. at 40°F. Again, even in the regions of residual fuel oils only, we have an Eastern fuel, such as Tarakan, which has a specific gravity of 0·94 at 60°F., but a viscosity of only 90 secs. Redwood No. 1 at 100°F., whereas most fuel oils with a specific gravity of 0·94 would have a viscosity of 600 secs. Redwood No. 1 at 100°F. or over.

Having already used the expressions "distillate" and "residual fuel," it might be explained that these expressions again provide another general classification. A distillate may range from a very light oil which is almost a kerosene to quite a heavy product as obtained in the process of lubricating oil manufacture. Similarly, some Eastern residual oils are almost equal to refined distillates in characteristics, and make excellent Diesel fuels even for comparatively small engines.

One could multiply almost indefinitely the details of a specification for fuel oil in order to get a clear indication of its characteristics, but although it might be necessary occasionally to have a complete analysis as a guide to the application of that fuel under very specialised conditions, it must be borne in mind that each added item

limits the range. Typical specifications of the three commercial grades mentioned would be as follows:—

	Gas oil.	Diesel oil.	Fuel oil. (1)	Fuel oil. (2)
Specific Gravity at 60°F.	·84/·86	·88/·90	·92	·95
Flash point (closed test)	Over 150°F.	Over 150°F.	Over 150°F.	Over 150°F.
Viscosity Redwood No. 1 at 100°F.	38/40	40/50	200	1,500
Water	Nil	Nil	Under 0·5%	Under 0·5%
Ash	Under ·01%	Under ·01%	Under ·05%	Under 0·1%
Hard asphalt ...	Under ·1%	·1 to ·5%	4 to 6%	6 to 10%
Conradson value	Under ·1%	·1 to ·5%	2 to 6%	4 to 8%
Cold test... ...	Below 0°F.	Below 0°F.	Below 32°F.	Below 32°F.

STORAGE

(*a*) General.

One of the most important advantages in the use of fuel oil is the ease with which it can be stored and handled, particularly where conditions for solid fuel would be impossible, *e.g.*, the double bottom of a ship. In land installations fuel oil can be stored in tanks either in the open, buried underground, or on any floor of a factory.

(*b*) Safety.

Before passing on to details, there is one point which should be emphasised. We are dealing exclusively with products which are extraordinarily safe from the point of view of fire hazard—much safer in fact than most people realise. Referring back to the commercial specifications, it will be seen that as far as fuel oil grades in this country are concerned, even the lightest, *viz.*, gas oil, has a closed flash point of over 150°F., and most fuels marketed, including gas oils, will be found to have their flash points at 170°F. and over. It is well to bear in mind, when comparing with American practice, that the light and medium "furnace" oils there are specified to have flash points as low as 110°F. in the one case and 125°F. in the other.

In Great Britain, therefore, the storage of fuel oils does not come within the scope of the strict regulations of the Petroleum Act, which refers only to comparatively volatile oils with a flash point below 73°F. It can also be appreciated why in America, particularly New York City, there are fairly stringent storage rules, including the compulsory burying of all tanks in town areas, since some of the so-called " fuel" or "furnace" oils are nominally kerosenes.

The use of oil fuel for heating modern buildings is increasing rapidly in this country, and the problem of what can be considered a safe method of storage sometimes exercises the minds of those responsible. The author has no hesitation in stating that, with

very reasonable precautions, a fuel oil storage tank may be placed above ground and even above the burner plant, without increasing the fire hazard to any appreciable extent. The basement is a very convenient position in which to have storage tanks, placed in similar recesses to those usually provided for solid fuel. Most burner plants can be fitted with a small pump which continuously draws oil from the storage tank, whilst in a gravity fed burner system a pump can be used to fill a small service tank as occasion demands.

As a general rule, the author is strongly averse to the buried storage tank for fuel oil. The chief argument for burying a fuel tank (apart from the extreme case, where there is no other space for it) would appear to lie in the fact that the oil could not overflow if a leak occurred, or if something went wrong with the plant connected to it. Such a tank, however, would always need a pump and the same possibility still exists of the pump continuing to run, in spite of something untoward happening elsewhere. In fact one can multiply the precautionary measures unduly, especially when it is considered that the modern oil-burning plant of the automatic type has usually a reasonable combination of safety devices to shut it down if it does not function correctly.

These remarks are not meant to imply that quite reckless measures can be taken over fuel oil storage, but as the author has met rather more undue nervousness than the opposite, he has thought it fit to lay stress on this aspect. A few of the most important general precautions from the point of view of safety can be stated as follows :—

(1) It is usually desirable when placing a storage tank within a building, to surround it with a reasonably oiltight catchpit capable of holding a minimum of, say, 80 per cent. of the contents of the tank, as a safeguard against a serious leak or the fracture of a valve.

(2) A vent pipe should always be fitted to a tank, of such a size as to allow rapid filling without undue pressure building up. The vent pipe should be led into the open air and have the end covered with gauze.

(3) Tanks in exposed positions where sharp frosts are likely to occur should have main valves of cast steel, preferably lagged. Bends, tees and similar fittings under the same circumstances are better of wrought iron or cast steel. Cases have arisen where pockets of water have settled out in valves or fittings, which have cracked in severe frosts.

(4) On comparatively large storage tanks (say, 100 tons capacity

and over), a valuable safeguard against the fracture of the main stop valve of the tank, is to have an internal foot-valve which can be operated by links from the outside (Fig. 1).

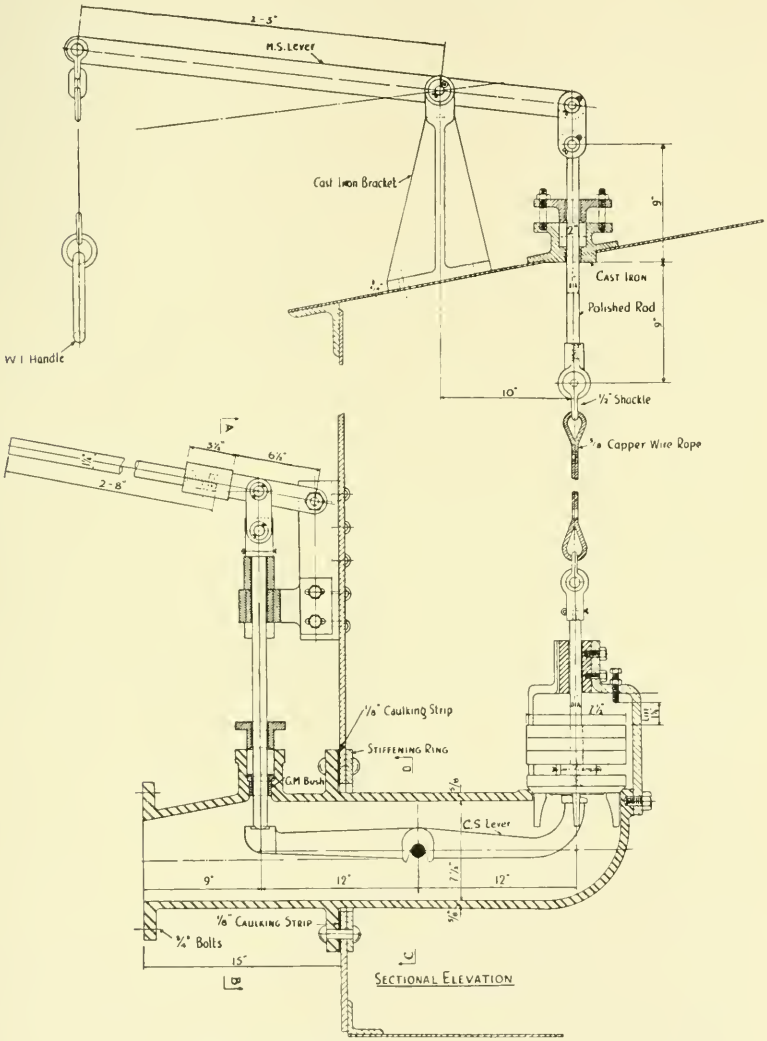

Fig. 1. Externally operated foot valve.

(5) For large storage tanks on very poor or waterlogged foundations, it is very desirable to have a flexible connection in the main pipe line leading from the tank.

(6) Gauge glasses should not be used on storage tanks of any

magnitude. With suitable precautions, heavy gauge glasses may be used on small service tanks, but these should be carefully protected from damage.

The above represent special safety measures in the storage of fuel oil, but other items to be dealt with later under handling, heating and transmission, may have safety aspects apart from their main technical significance. The author has also omitted special reference to marine practice, since the whole subject is excellently covered by Lloyd's Rules for the Burning and Carrying of Oil Fuel. (Section 49, page 62.)

(*c*) Types of Storage Tanks.

It is not proposed to give in this paper any of the usual statistics for capacities of different sizes of oil storage tanks, since in all cases the calculations can be made from simple mensuration. The general features of different groups are dealt with as follows:—

(1) Large vertical cylindrical steel tanks, as used by oil companies themselves, are frequently installed by users who may find it advantageous to receive bulk supplies from tank vessels or barges. This type of tank would be advisable for capacities of, say, 100 tons and over. The general constructional features can be seen from Fig. 2, which represents an exceptionally large tank from the point of view of the user, *viz.*, 64 ft. dia. by 29 ft. 6 in. high.

A swing pipe is shown, but is hardly necessary unless the user wishes to blend different grades or draw off from any special layer. It may, however, be looked upon as a safety device, since it can be lifted clear of the oil if the main valves were to fracture. In that case the previously mentioned foot valve would, of course, be a refinement.

It will be seen also that the tank has only one main 8-in. outlet connection. For the average user it is sometimes advisable to have two master valves and the corresponding stools, since it simplifies the manifolds and enables him conveniently to draw supplies from a tank even while it is being filled by the supplier.

A typical installation arrangement for a large works in this country, with three vertical cylindrical tanks, each of 40 tons capacity, is shown in Fig. 3.

Quite a satisfactory type of foundation for a tank of this nature is well-rammed aggregate or broken brick, of a depth depending on the nature of the soil, with a top layer of 6 to 9 in. of fine sand for the bottom plates to rest on. A neater arrangement, of course, is to lay a reinforced concrete raft and place the sand on that. Where the nature of the ground is such that it will not stand the requisite

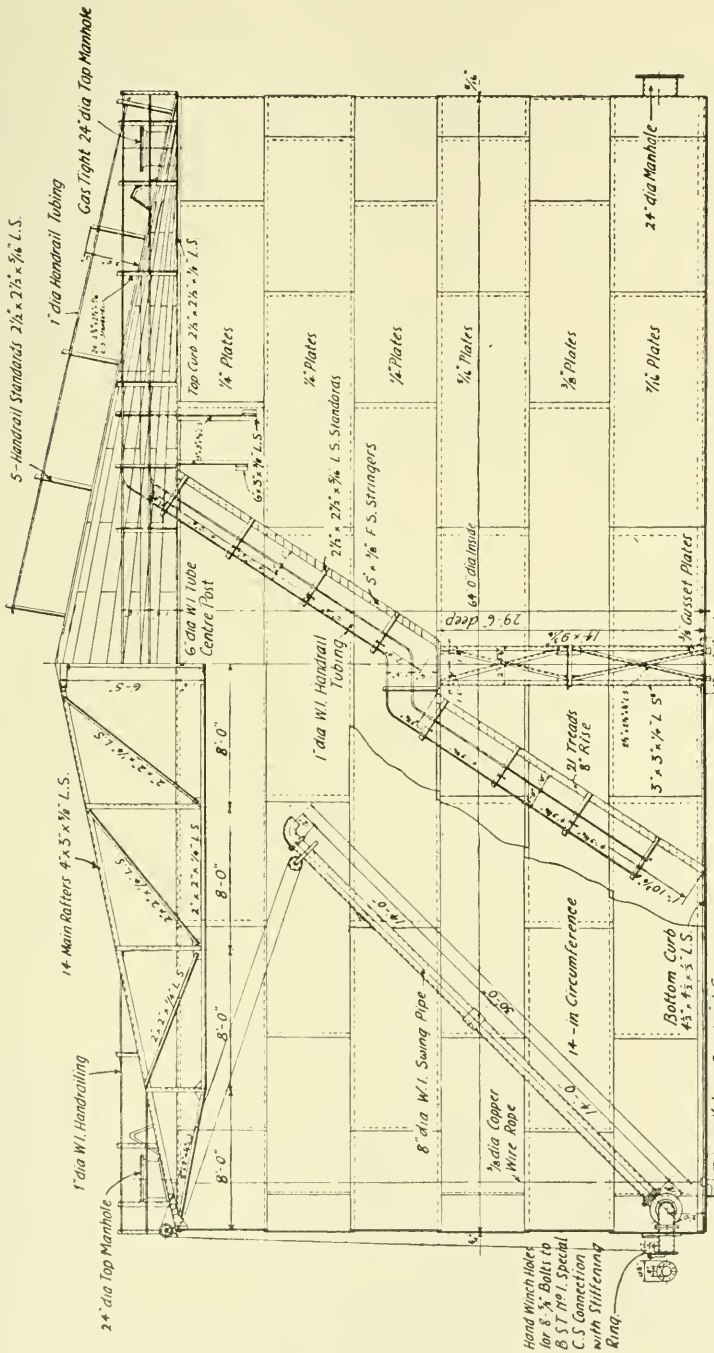

Fig. 2. Large fuel oil storage tank.

load per square foot, the usual special precautions are required in making up suitable sub-foundations.

It is advisable to let a large tank settle down on its foundations after filling it with water, this being particularly necessary if there is any doubt about the foundations. The subsidence (if any)

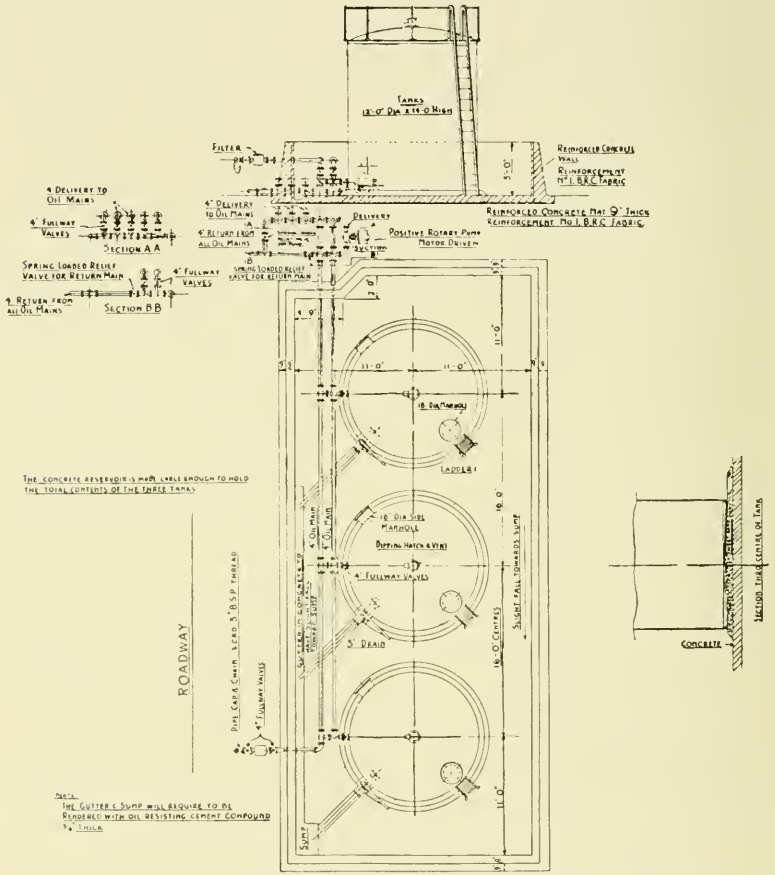

Fig. 3. Typical user's installation. Three 40-ton tanks.

of the tank should be measured from day to day until it becomes negligible.

The four large manholes, two on the circumference and two at the top, shown on the drawing (Fig. 2) should be particularly noted, likewise the bottom drain valve.

(2) Subsidiary Tanks. Apart from the main tanks described in the previous paragraph, we have many varieties of smaller tanks

for users who would take rail tank car or road wagon deliveries. These would range from the 3-ton tank of a central heating installation at a private house to, say, 40 tons at a works.

Steel cylindrical or rectangular tanks are by far the best suited for this purpose. For the former, an old boiler shell with the necessary alterations will often serve excellently. The rectangular tank must be carefully stayed internally, and the supports must be sufficient in number not to throw undue stresses on the bottom.

To reduce cost, the shell of a steel tank can be reasonably thin, if due regard is paid to the method of support. The cylindrical tank with dished ends, if correctly designed, should need no internal staying. A large tank, 30 ft. long by 9 ft. dia., holds about 40 tons of fuel oil and may be of $\frac{1}{4}$-in. plate only on the body, with $\frac{3}{8}$ths thickness on the dished ends. These dimensions apply to the tank resting horizontally. There is no objection to using deep cylindrical tanks on end, but allowance should be made for the greater stresses.

Where tanks have to be placed in basements of buildings, and there is no means for getting a complete tank on to the site, sectional rectangular tanks are very convenient. These are usually a little more expensive than the ordinary tank. The joints may be made with lead strips caulked in, or with a special oil-resisting cement Tanks are occasionally installed under similar circumstances by welding them up on site. The obvious objection to this is that they would need cutting up if removal were necessary at a later date.

Riveted tanks in these comparatively smaller sizes are being gradually replaced by welded ones, the advantage of the latter lying in oil tightness. Oil is extremely searching, and badly filled rivet holes show up very quickly in annoying leaks which are almost impossible to make good. This also applies to seams on thin walled tanks. It will be noted that Lloyd's Rules for ships' tanks to contain oil insist on double riveting. Particular care is necessary in the construction of pads for outlet or drain on that portion of the tank subjected to the full head of oil. Such pads should always be reinforced by a backing plate, and as an added precaution against leakage, pad and backing plate may be welded to the tank plate. Large manholes flat on the sides of rectangular tanks should never be used in the manner commonly seen on domestic water tanks—they almost invariably cause an irritating weep of oil which no jointing or tightening of nuts will eliminate.

Concrete tanks can be used for fuel oil, but very great care is required in construction. It is essential to have a special facing of material, impervious to oil, on the whole internal surface. This

is due to the disintegrating effect of oil on ordinary concrete. There are a number of proprietary cements on the market which can be used as a rendering and, from the author's experience, most of these are quite satisfactory when applied under the makers' guidance for a facing of about $\frac{1}{2}$ to 1 in. thickness, according to size.

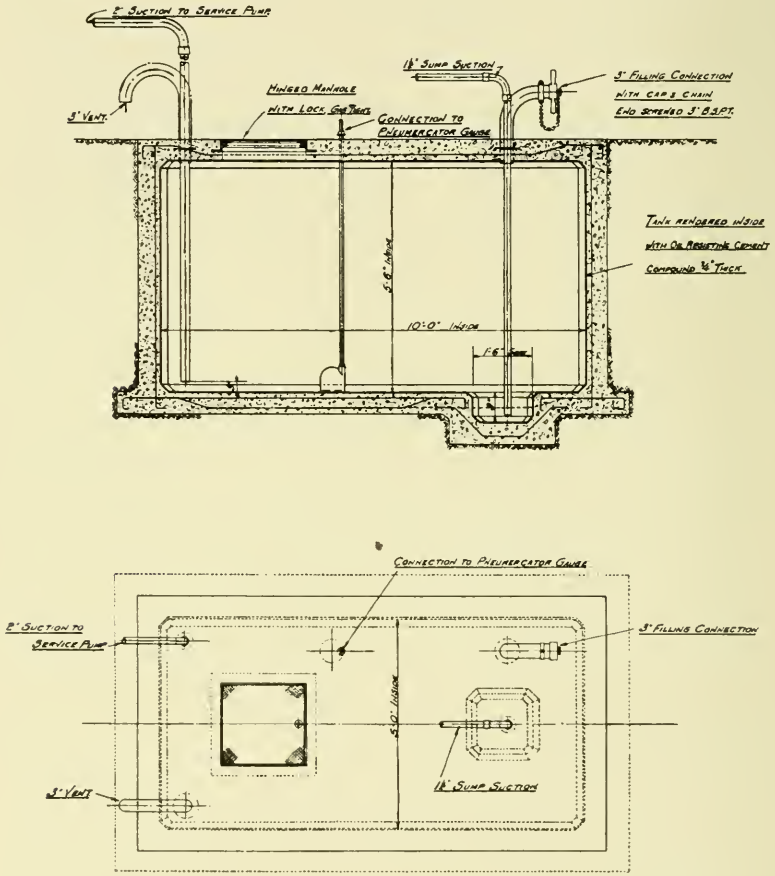

Fig. 4. Small concrete fuel oil storage tank.

No concrete tank, however carefully rendered on the interior, will stand oil storage, if the foundations are unsound or if the general construction is such that cracks are likely to occur. It is, therefore, necessary to choose a site and construct the tank carefully from this point of view. A typical small concrete storage tank is shown in Fig. 4.

The author has already referred to the buried storage tank as being objectionable. This is chiefly on the score of accessibility for cleaning and drainage. Where, however, there is no alternative, a tank may be buried in the ground, but it is advisable to give the outside two good coats of bitumastic paint. The soil should be examined for excessive free acid, since very rapid corrosion has been known to occur where seepages from chemical liquids have reached the buried tank. A buried tank should also be laid with a slight fall to one end, and a suction pipe led down to the extreme bottom corner at this end, so that any accumulation of water can be pumped out. Well-fitting covers should be provided over inspection or dip manholes, to prevent the entry of dirt and rain. The ideal arrangement for a buried tank is to build a brick or concrete pit sufficiently large to take a steel tank, and yet allow sufficient room all round the latter for inspection and occasional draining.

The small gravity service tank should present no difficulties, and it is usually convenient to fit this up on a light steel trestle. A typical arrangement is shown in Fig. 5. As such a tank would usually be pumped up from a distance, it is advisable to fit an overflow pipe to return excess to the main storage tank. A useful arrangement sometimes, when pumping into service tanks from a distance, is to have a float operated electric bell, wired to ring at the pumping point.

HANDLING

(1) Heating.

Fuel oil is heated with the following objects:—

(*a*) To reduce the viscosity for pumping purposes.

(*b*) To improve the burning characteristics in a furnace or engine combustion chamber.

(*c*) For cleaning purposes to facilitate water removal by settling or centrifuging.

The amount of heating required will depend on the grade of oil. Generally speaking, gas oil and Diesel oil can be handled cold under nearly all conditions, for the viscosity, even at 0°F., rarely exceeds 150 secs. Redwood No. 1. It is also not improved to any appreciable extent by heating for burning purposes. In fact, there are cases where any attempt at heating would cause difficulties due to gas locks.

The same remarks apply to most commercial Diesel oils, but a comparatively heavy distillate is sometimes supplied under this designation, and if it is to be stored or handled in exeptionally cold weather a little heating may be advisable.

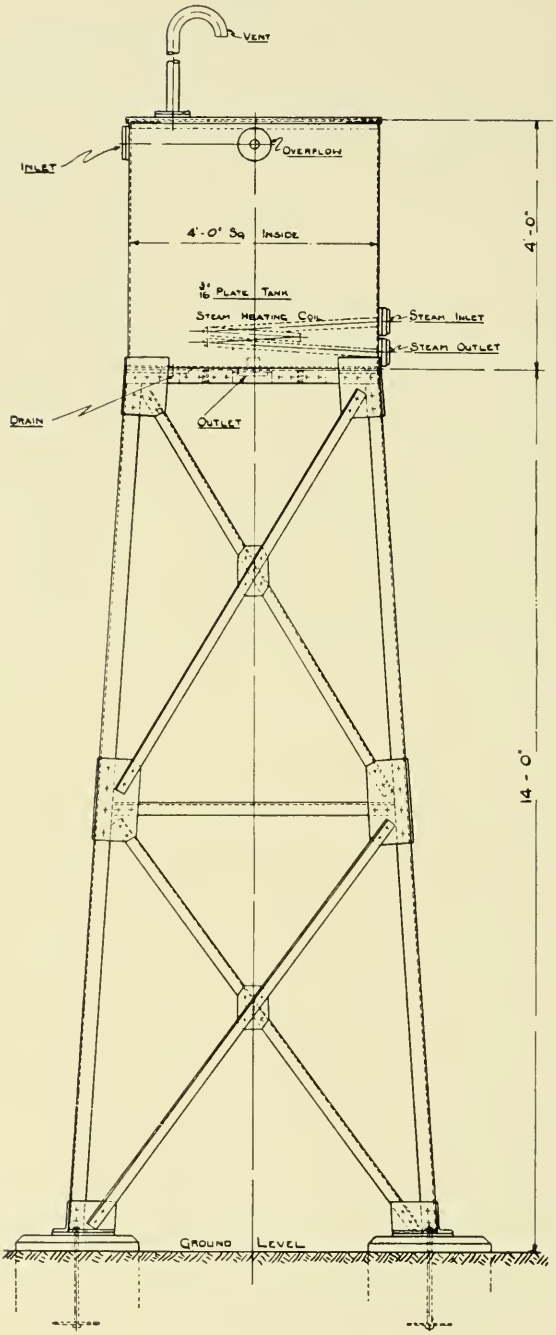

Fig. 5. Fuel oil gravity service tank on trestle.

Even heavy fuel oils can be handled quite cold as far as pumping is concerned if due provision is made, but naturally the limits

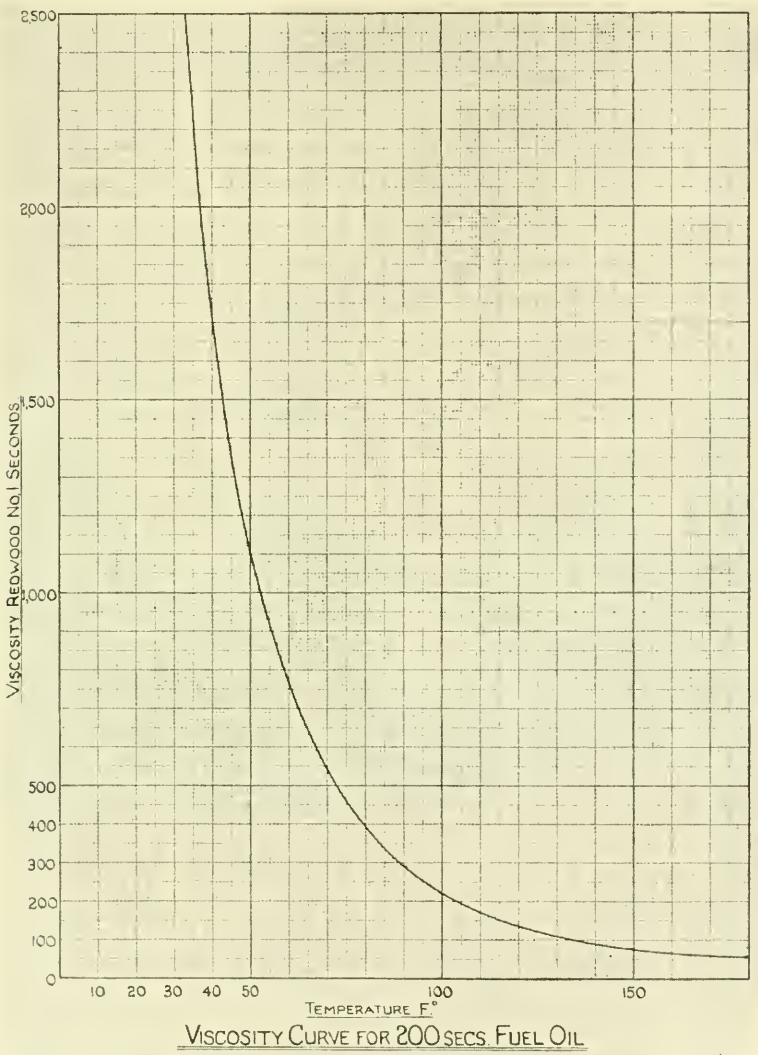

Fig. 6. Temperature viscosity curve of typical light fuel oil.

between which this can be done are comparatively narrow. It is still generally advisable to heat the oil if only to save power, and

in any case final heating will nearly always be necessary to improve the burning qualities. A typical viscosity-temperature curve for a light fuel oil is given in Fig. 6, and for two heavy grades of Mexican fuel oil in Fig. 6A. It will be seen how rapidly the viscosity rises at temperatures below 100°F.

Regarding methods of heating, the most common is to use a steam coil inserted in the storage tank, which can be supplemented by line heaters or steam coils in service tanks according to the conditions prevailing. On a large installation the main storage tank

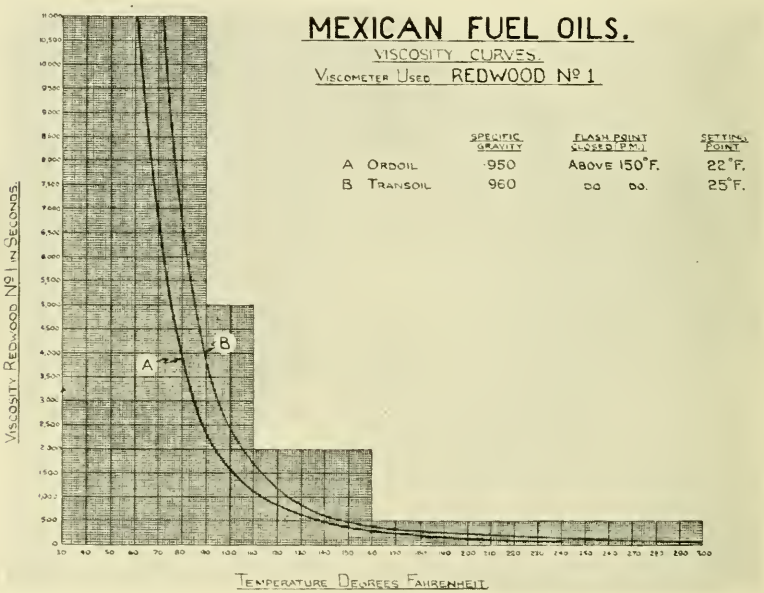

Fig. 6A. Temperature viscosity curves for two heavy grades of fuel oil.

would be only lightly heated to a convenient pumping temperature, depending on the grade of oil used and the section or delivery head. For this purpose a flat grid coil or system of coils is used, placed as low down in the tank as possible. A typical arrangement is shown in Fig. 7. The amount of heating required being usually only moderate, a rough approximate figure is about 0·3 sq. ft. of steam coil heating surface per ton of oil for large tanks of 1,000 tons and over, increasing to, say, 0·5 sq. ft. per ton for smaller sizes. It is not advisable to use these low figures for very viscous oils in exposed positions, where temperatures higher than 100°F. require

maintaining, or where a rapid heating up is required. In all such cases the coils should be definitely designed for the specific purpose.

Unfortunately, there is very little accurate information on the overall heat transference coefficient for a steam coil in a tank, where the oil has no definite velocity. The author has found, however, that a safe working factor is 20 B.Th.U.'s per square foot per hour per °F. difference. The specific heat of fuel oils can be taken with sufficient accuracy at 0·5 for light oils down to 0·45 for the heavier grades. It is, therefore, a comparatively simple calculation to

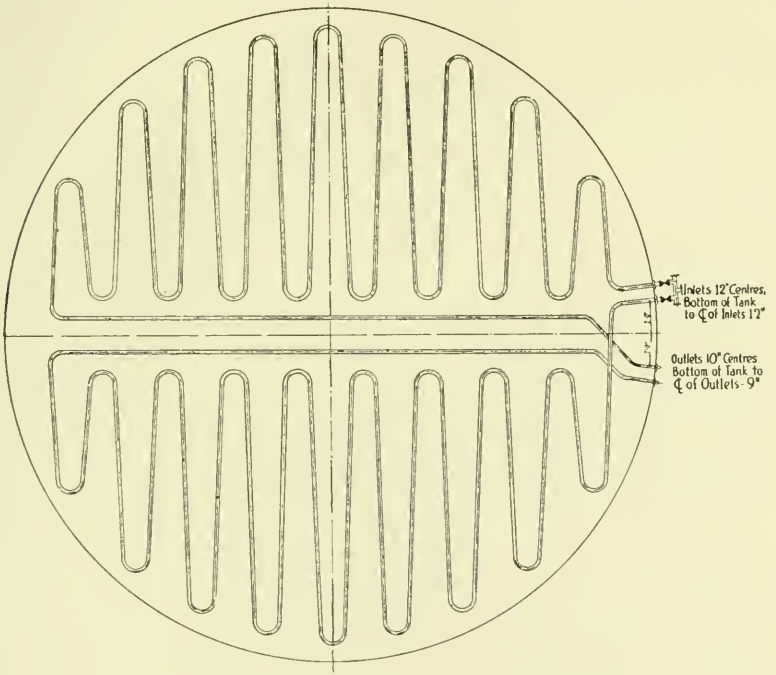

Fig. 7. Flat grid steam coils for large storage tank.

determine the amount of heating surface required to raise so many tons of oil a given number of degrees in a given time. It is necessary to apply a correction for the heat lost through the walls of the tank by radiation and convection during this process. When large tanks are slowly heated up in the open, this heat loss may be of the same order per hour as that absorbed by the rise in oil temperature. The factor for the heat loss will obviously depend on the exposure, wind velocity, nature of tank surface, mean temperatures, and so on. A rough practical figure for approximate calculations is to take

1 B.Th.U. per square foot per hour per °F. difference between the oil and the outside air for temperatures up to 100°F., increasing this generally with the temperature on the same basis as the losses from a bare hot water or steam pipe.

Apart from keeping oil at a moderate temperature in main storage tanks, there are many applications where fuel oil requires heating preparatory to burning. In such cases this is economically carried out in line heaters placed close to the point at which the oil is to be used and designed for the quantity which is to be dealt with within a given time.

For comparatively small plants and for temperatures below the

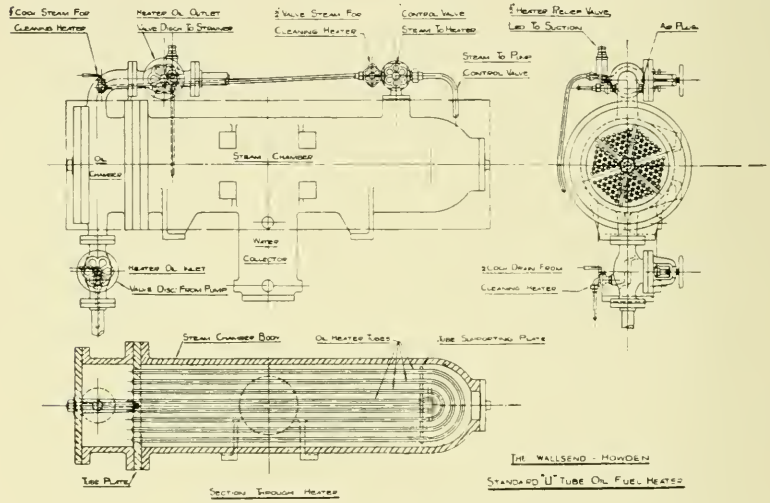

Fig. 8. High-pressure oil fuel heater.

flash point, say up to 160°F., an effective oil heater can be constructed on the lines of a feed water heater for boilers. It usually takes the form of a cylindrical vessel inserted in the oil-pipe line with a steam coil inside the body, the amount of steam coil surface required being calculated on the same basis as mentioned above. Such heaters should always be provided with a drain cock at the lowest point for water, a vent cock at the highest point to release separated air or oil vapour and, of course, a thermometer. It is very desirable to fit the heater with thermostatic control, especially where steady flow to an oil burner is required. There are quite a number of effective thermostatic valves on the market, which are usually direct acting on the steam supply to the coil.

For mechanical atomising burners, with viscous fuels where a high oil temperature is required, exceeding the flash point, it is necessary not only to provide ample heating surface, but the oil should be under pressure while it is being heated. The heaters in this case have the oil constrained to pass through tubes in two passes, with the steam space surrounding them instead of the reverse method described above. A typical heater of this type, used in conjunction with the Wallsend system of pressure oil burners, is shown in Fig. 8. The oil, being forced through positively, has a well-defined velocity, and hence the overall heat transference coefficient is distinctly better than in the case of a large body of oil. It is better, even in this case, not to take a higher factor than 20 B.Th.U.'s per square foot per °F. difference, since a margin is usually required for special oils when a particularly high temperature is wanted. The temperatures for which such heaters are employed vary from 130°F. to 300°F. One must be careful not to overlook the fact that where these heaters may be used on a low pressure steam system, the high temperature sometimes essential cannot be attained.

The author has only referred to very approximate rules for steam heating surface calculations where no accurate technical data is available. Some good work is being done in this field by several experimenters, and for details of conditions which can be calculated, the reader is referred to "Heat Transfer and Evaporation," by W. L. Badger (The Chemical Catalog Co. Inc.), and a paper by F. H. Morris and Walter G. Whitman on "Heat Transfer for Oils and Water in Pipes" (Ind. Eng. Chem., 1928, *20*, 234).

The above so far has dealt with steam only as a method of heating oil, since this is probably the most common method in use. The author proposes to mention only briefly such other methods as are of practical interest. Hot water can be used in the same way as steam, and this is sometimes the only means available on hot water boiler plants or on engines where the cooling water may be pressed into service. Only moderate temperatures can be reached and the factor of heat transference is very low.

Electricity can be used quite successfully for comparatively intermittent work, or as an auxiliary to another method for starting-up purposes. It is, of course, distinctly more costly in running expenses than steam. The cost of heating oil by electricity, say 100°F., would add approximately 3s. per ton to the price, with electricity at 1d. per unit. The usual type of electric heater consists of multiple-bladed resistance elements, wound on mica or similar formers, and encased

in copper sheaths. It would probably be better to have these sheaths of steel, in order to resist any possible corrosive effect of sulphur in the oil. In the author's experience, however, the heater blades fail under continuous use, due to the accumulation of carbon on the outer surface, which, resulting as it does in a high temperature gradient through the metal, burns it out. It is essential to remove electric heaters periodically for inspection and cleaning. Where electric heaters can be used for auxiliary purposes intermittently, they are very convenient and can be fitted readily with a thermostatic cut out.

In many furnace installations, oil is preheated by taking advantage of the immense amount of waste heat usually passing away. Great care is necessary in making the necessary provision, and it is generally not advisable to do more than pick up some heat from a furnace crown or side walls by running the oil line in proximity thereto. The difficulty with this method, and others of a similar nature which rely on direct radiation from a furnace, lies in the variable temperature which is likely to be attained.

Direct fired gas heaters are sometimes used, but these should be restricted to starting-up appliances only.

(2) Cleaning and Drying.

All commercial fuel oil grades are likely to contain water varying from a trace to perhaps 1·0 per cent. in heavy bunker fuels. Even when delivered free from water, exposure of tanks to rain water or the ordinary humidity of the atmosphere will cause a small accumulation. It will be realised that in a storage tank without any special provision, such water, however small the quantity, will accumulate until quite a considerable amount settles to the bottom.

It is interesting to point out that water completely emulsified with fuel oil causes no difficulty in burners or similar devices, in fact emulsions containing up to 50 per cent. of water have been used successfully for boiler firing. It is only when free water is likely to come through in intermittent spurts that very serious trouble may occur. One should not, therefore, rely on the emulsion remaining unbroken, and it is better to encourage the water to settle so that it can be removed.

In conjunction with water, every fuel oil without exception will tend to throw down, sooner or later, a quantity of "sludge." Such sludge usually forms very slowly indeed, and the average user will overlook it until it gets to a sufficient quantity to come over with the oil. The result is usually a complaint to the oil supplier

that the last load was badly contaminated. It is preferable to keep drawing off water and sludge from the bottoms of tanks at, say, monthly intervals, with a complete emptying and cleaning out every year.

The provision of strainers is very desirable in keeping down the tendency to sludge formation, since particles of foreign matter seem to act as nuclei in the process. Foot valves with surrounding strainers should not be used with fuel oil, since they are liable to get choked in time. It is better to have a fairly coarse strainer on the delivery line to the main storage tank and finer strainers on individual service lines. So called "Duplex" strainers are an advantage, since one can be used while the other is being cleaned.

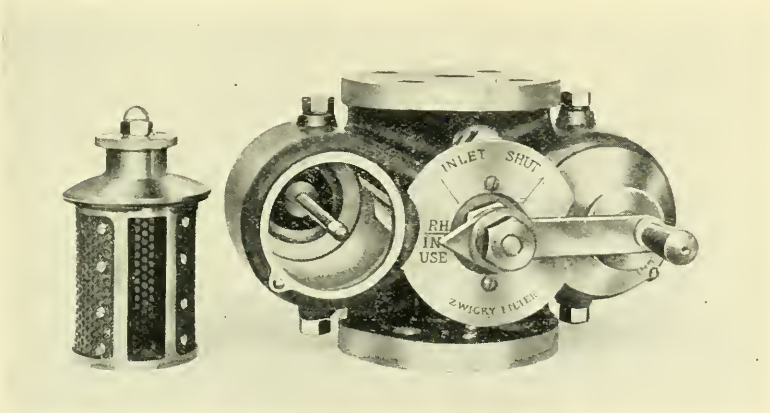

Fig. 9. Typical duplex oil filter.

A typical design is shown in Fig. 9. A straight-through strainer for comparatively large pipe lines, where the duplex type would be too costly and cumbersome, is illustrated in Fig. 10, and has an easily removable bolted cover for getting at the strainer casing. The latter is also capable of being tightened up against a jointed face to prevent leakage. An interesting new strainer which has been found successful for fuel oil is the "Auto-Klean," illustrated in Fig. 11. It has the advantage that cleaning can be effected at any time from the outside by the turn of a handle.

The centrifuging of fuel oil is undoubtedly the most successful method of obtaining a thoroughly clean and dry oil for such applications where this is essential. To be thoroughly effective, the oil requires heating to as high a temperature as possible below the

flash-point. It is comparatively expensive in power and steam, and the method is only warranted in connection with the delicate atomising devices of a Diesel engine. It does not, moreover, as is sometimes claimed, reduce the chemically combined ash content of the oil, or the hard asphalt.

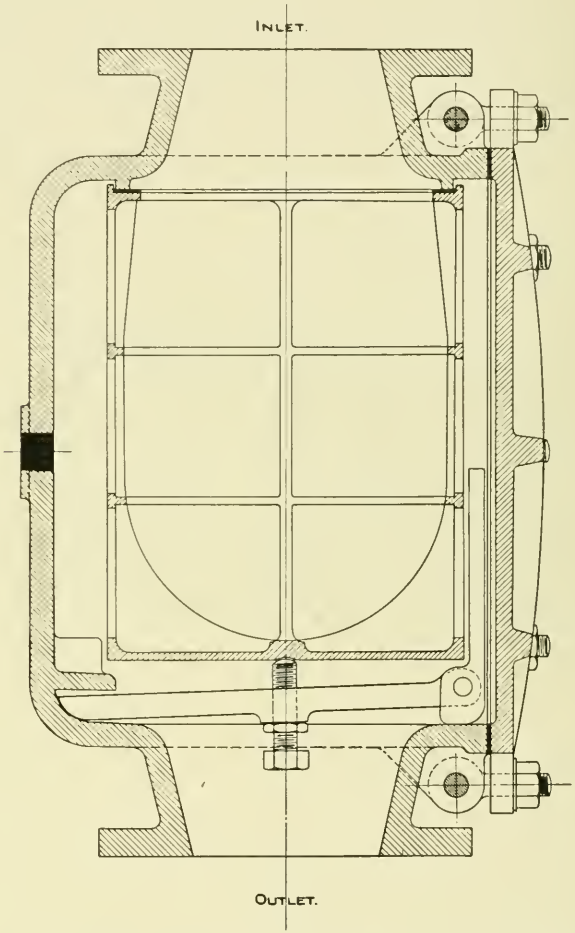

Fig. 10. Straight-through oil strainer (Messrs. Simmons & Hawker).

(3) Jointings and Packing.

Oils of all kinds are very searching in finding leaks in storage tanks, pipe lines and pumps. It is unfortunately rather taken for granted by some engineers that oil weeps are unavoidable, whereas

it must be clearly pointed out that an oil fuel system can be made as thoroughly tight as a water system.

Flanged joints on pipe lines are more satisfactory than couplings or unions, and it is advisable, especially for high pressure lines, to make practically a metal to metal joint, with a thin piece of jointing material. For cold oil almost any jointing material will do, provided it is thoroughly impregnated with a petrol resisting compound, such as shellac in methylated spirits. For hot oil it is better to choose one of the best grades of so-called asbestos jointing, which will be improved by the treatment mentioned before. The better the metal to metal facing, the more effective will be the

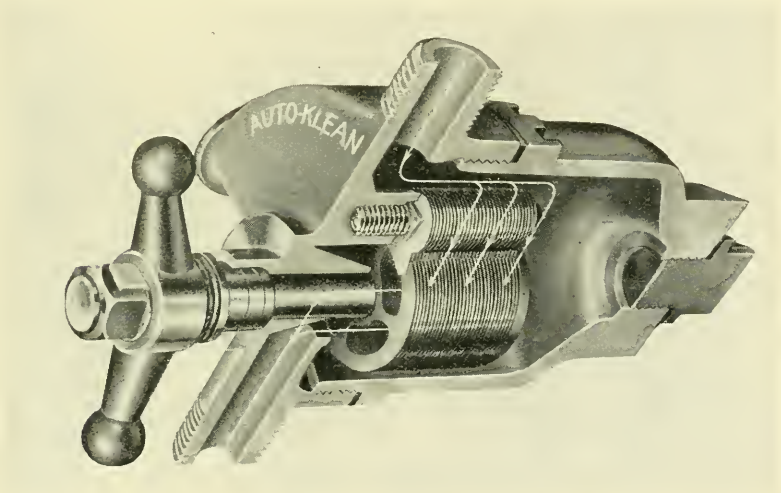

Fig. 11. "Auto-Klean" fuel oil strainer.

joint, and on badly machined surfaces no amount of jointing will be of lasting use.

The barrel socket presents a more difficult problem in respect of oil tightness. The ordinary plumber's expedient of red lead and hemp will not do. The tightening of a running coupling for oil pipe lines should always be carried out on well-fitted threads, which should be painted with a shellac compound before being finally screwed home. The ordinary cone-seated union may be quite a troublesome source of oil leakage, unless carefully ground and fitted. The self-tightening union shown in Fig. 11A is remarkably effective.

Pump and valve glands require careful packing of the right kind.

Quite a reasonably effective combination is ordinary white cotton packing steeped in soft soap. This latter material has a curious hardening effect under the influence of oil, which thus makes it suitable for this purpose. The author has also found the proprietary "S.E.A." rings very effective and durable. These rings are of "U" section after the manner of hydraulic leathers and thus have a certain self-sealing action under pressure.

(4) Measurement of Oil.

With the exception of gas oil, fuel oil in this country is sold by the ton. For checking deliveries, therefore, by far the most effective method, in the case of rail cars or road wagons, is to pass the vehicle over a weighbridge before and after discharge. Where this is not possible the method of tank dipping is probably the most reliable, particularly for the vertical cylindrical tank. It is desirable, therefore, to calibrate a main storage tank very carefully as soon as it has settled down on its fundations. As a dipping tape can be read quite easily to the nearest 1/10th of an inch, or even less with care,

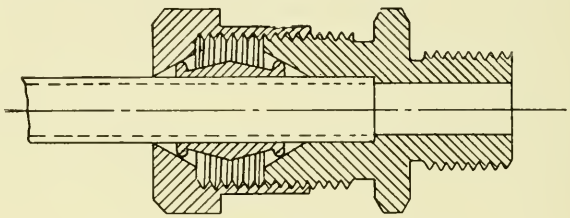

Fig. 11A. Self-tightening pipe union.

the error on large deliveries even in big tanks is not likely to be great.

Small tanks of awkward shapes for calculation purposes may be calibrated by filling with standard measures and engraving a suitable dip rod or tape, but a cumulative error is liable to occur unless this process is carefully carried out. Although it may appear very tedious, it is sometimes a quicker and more reliable method than working out the calculations.

The "Pneumercator" is a very convenient method of measuring oil in tanks or checking against some other method. It can be described briefly as a diving bell device with a sharply defined overflow placed at a fixed point on the bottom of a tank. The trapped air transmits a pressure to a mercury gauge, equivalent to the head of oil above the fixed overflow level of the diving bell. To ensure that the oil in the latter is always at the same level, the air system is pumped up before a reading, and on a small installation this can be done with a few strokes of a hand pump. Since the

mercury column balances a definite head of oil, the gauge, if calibrated in tons, will require no correction for specific gravity. This is an exceptionally valuable feature for oil where specific gravity changes can be quite considerable, either with different deliveries or due to temperature changes. A diagram showing the arrangement of such instruments aboard ship in connection with double-bottom tanks is shown in Fig. 12. Without detracting from the enormous advantages and convenience of this instrument, and those of similar type, it must be remembered that 1 ft. head of oil has to be read approximately on the equivalent basis of 0·8 in. mercury. What would appear, therefore, as quite a coarse accuracy of 1/10th in. on the dipping tape, requires an equivalent reading to ·0067 in. on the gauge. Where such accuracy is required,

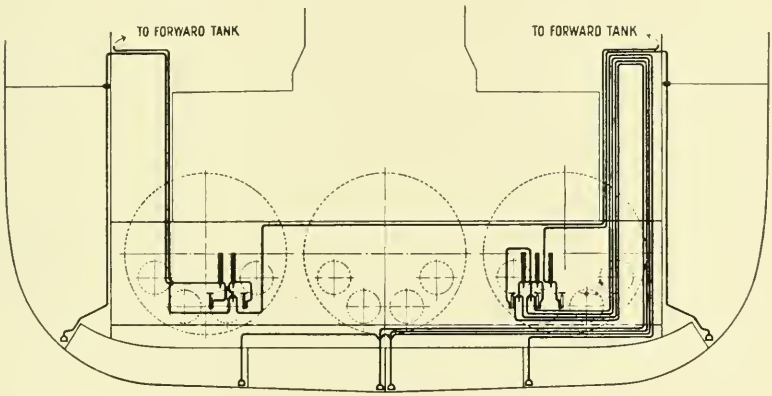

Fig. 12. Pneumercator installation for ships' tanks.

however, a specially wide mercury column can be had with a vernier scale, so that it is equal to a barometer in this respect. With such an arrangement the makers claim to be able to read to ·002 in. On the whole, these instruments are in the author's opinion very satisfactory indeed.

The oil meter in its many varied commercial forms is an excellent instrument for checking consumptions at various points in a works. Most good-class makers will guarantee the accuracy to within plus or minus 1 per cent. It is essential to have a meter of the positive displacement type. The internal parts should be of close-grained cast iron, special alloy steel, or aluminium, to resist the action of oil. The author does not consider that even the most accurate meter can take the place of direct weighings or careful tank dips on bulk

deliveries, but it is excellent as an approximate check. Being strictly volumetric, a correction has to be made for specific gravity to convert to tons, and care must be taken against false readings due to occluded air or vapour.

The most marked value of the oil meter, however, which is not readily given by other methods, is in operative control of furnaces as a check on consumption. Even with a comparatively high error of 2 per cent., the variations in consumption can be noted under different conditions and the results of improvements or careless operation detected.

Transmission

It would be entirely beyond the scope of this paper to give a detailed account of the many different kinds of pumps which can be used for the transmission of oil. It is only hoped here to touch on the practical considerations in laying out a pumping plant to deal with fuel oils according to grades. The question of gravity transmission as distinct from pumping resolves itself purely into a mathematical calculation, which will be dealt with in outline later.

The pumps used for fuel oil may be of the following types:—

(1) Steam reciprocating of the single line or "duplex" type.
(2) Single, double or treble barrel plunger pumps (belt or gear driven).
(3) Positive rotary pumps.
(4) Hand pumps, rotary or semi-rotary.

There is no reason why the centrifugal pump should not be used for the very low viscosity oils such as gas oils, provided the pumping conditions are such as would allow the use of this type with water. It is advisable, however, when putting down pumping plant for fuel oil to allow for the worst conditions, particularly the highest viscosity likely to be attained under given weather conditions. It is not often, therefore, that the centrifugal pump can be used for fuel oils of even the lighter grades.

(1) The direct steam-operated piston pump is still very largely used for fuel oil, particularly the heavier grades. It has the advantage of simplicity, ease of operation and comparatively low initial cost. When kept in proper adjustment, a good vacuum can be dealt with, and on the score of reliability under exacting conditions this type is hard to equal. It suffers, however, from one serious drawback, *viz.*, the heavy steam consumption. As is well known, the average steam pump operates with practically no expansion on the steam in the smaller sizes, and even where cut-off is provided

it is not possible to make it very early. Compounding has been used with success in the larger pumps, but for the average user the expense would be hardly warranted. Where, however, steam pumps can be fitted, so that it is possible to absorb the exhaust steam on process work, the heavy consumption ceases to be such a serious drawback.

The author has attempted to obtain some general approximate formula for the steam consumption per ton of oil, but the results vary considerably with the type of pump, the grade of oil, the steam and oil pressures. A very rough formula is:—

$$S = 0{\cdot}4\ PIV$$

where S is the steam consumption in lb., P the total pressure head (suction and delivery) against which the pump works, and W is the tons of oil pumped. This formula must not be looked upon as being mathematically accurate to any degree, since the results of the formula may be easily 100 per cent. wrong on low pressures with incorrectly proportioned cylinders. It is also meant to apply to the ordinary steam duplex pump only without expansive use of the steam. A still more simple figure to bear in mind, just for a very rough general guide, is "30 lb. of steam per ton of oil when delivering at, say, 75 lb. pressure." Most well-designed steam pumps will give consumptions well below this amount, but it gives an upper limit in tentative estimates.

For compound and triple-expansion steam pumps under special duties, the following figures are quoted:—

"Pump end 8-in. dia.
Steam cylinder 22-in. and 38-in. dia.
All 36-in. stroke.

The above pumps were of the compound tandem direct-acting type, each to deliver 8,000 gallons per hour at 14½ D.S. per minute against 1,000 lb. per sq. in. pressure when supplied with steam at 120 lb. per sq. in.

Steam consumption 49 lb. per B.H.P. per hour.

Triple-expansion tandem pumps are supplied as follows:—
Pump end 10-in. dia.
Steam cylinders 16½-in., 25-in. and 38-in. dia.
All 30-in. stroke.

Each pump to deliver 8,700 gallons per hour at 12 D.S. per minute against 600 lb. per sq. in. when supplied with steam at 150 lb. per sq. in.

Steam consumption 33 lb. per B.H.P. per hour."

For oil fuel the steam duplex pump should have distinctly different

characteristics from that supplied for water. The pump pistons should be of close-grained cast iron and the pump rods should be steel instead of the more common bronze. Pump cylinder liners are preferably of gunmetal. The valves should be of ample area, the best types having these arranged on two decks with removable plates and ample inspection doors. An air vessel on the delivery side of the pump is always desirable, except in the very smallest sizes.

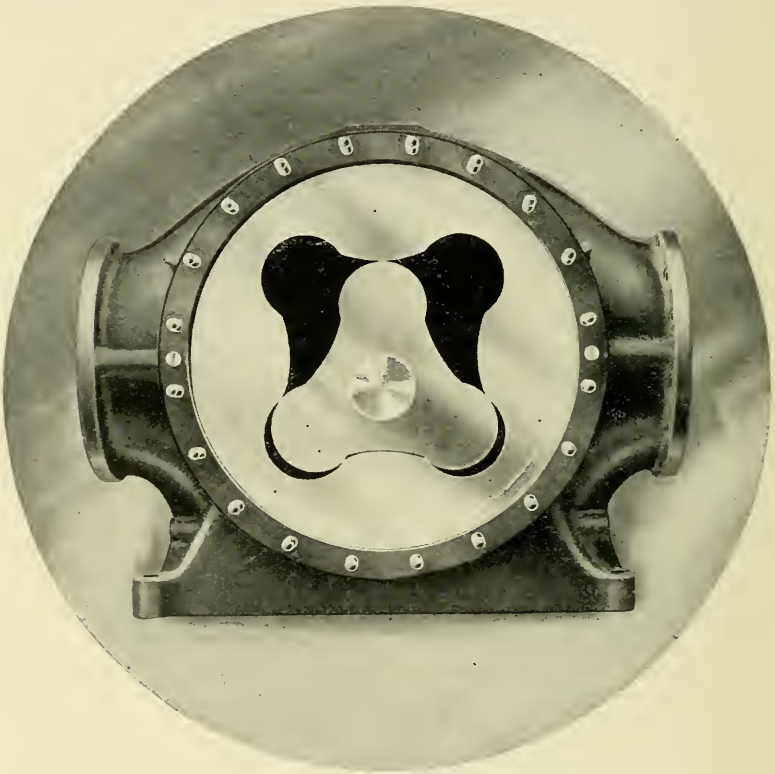

Fig. 13. Positive rotary pump (Feuerheerd principle).

(2) For cases where types of prime movers are available other than steam, the barrel plunger pump, arranged with suitable gearing or belt drive, is eminently suitable for oil, particularly at high-delivery pressures. Increasing use is being made of these pumps driven by oil engines, which latter are frequently far less costly to install and operate than electric motors. For small pumps in localities where electricity is cheap and the running of expensive cables is unnecessary, the electric motor forms a convenient drive.

In connection with the latter, however, the greatest care should be taken in choosing the switchgear. Owing to the heavy starting torque usually required, except on the least viscous grades, the switchgear must allow for gradual running up to speed, unless the

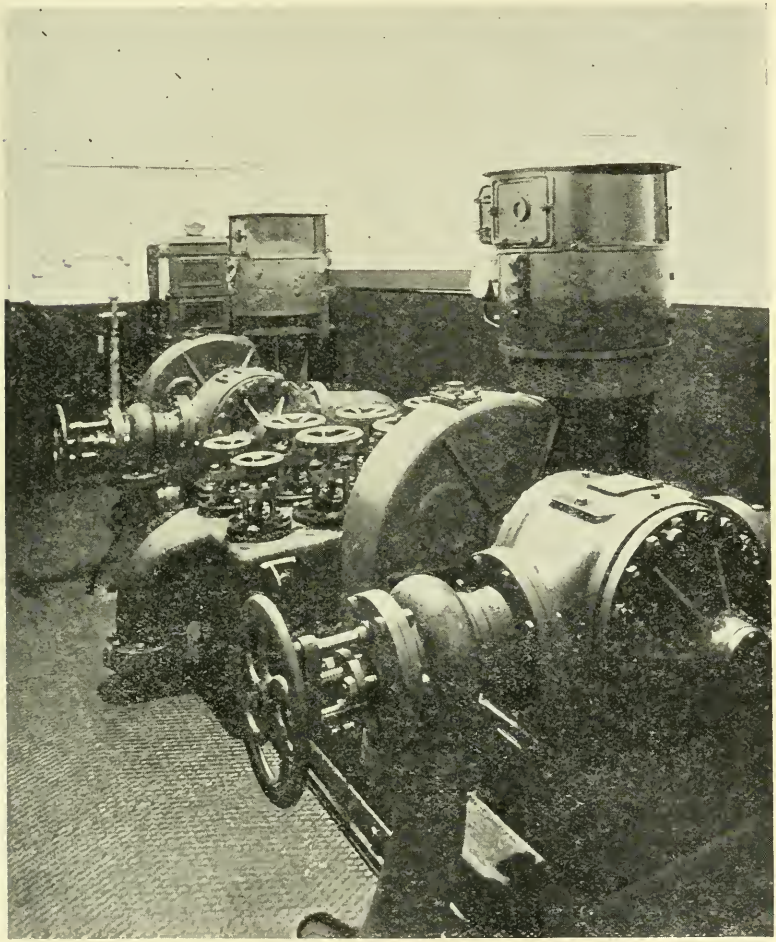

Fig. 14. Diesel oil pressure pumps on M/V "Christian Huygens."

mechanical equivalent of a slipping belt or clutch is provided. With A.C. current in particular, it is essential to have a slip-ring motor and a slow-motion variable-speed controlling resistance. The same remarks apply to the positive rotary pumps mentioned below.

(3) Positive rotary pumps are very successful for fuel oil even of the most viscous grades. As in the case of the barrel-plunger pumps, they are very conveniently driven through gearing either by electric motor, steam engine or oil engine. These pumps are remarkably compact even for heavy duties, and as they can be run at comparatively high speeds the amount of gearing down is not considerable. They give a very uniform discharge and with worm gearing can be made almost noiseless.

One of the leading makes is that on the Feuerheerd principle, which is illustrated in Fig. 13. An arrangement of two of these pumps driven through worm gearing by electric motors with vertical armature shafts is shown in Fig. 14. (Diesel oil transfer pumps on M/V. "Christian Huygens.")

For works installations it is becoming a very common practice to use small electrically-driven oil pumps even for discharges of a few hundreds of gallons per hour where previously hand pumps would be employed. The saving in time and labour is very marked. Such pumps can be used either for the periodic filling of gravity service tanks or for continuous feed to a system of furnaces on a range. In the latter case it is only necessary to by-pass the suction and delivery lines at the pump through a spring-loaded enclosed discharge relief valve to obtain any desired uniform pressure on the oil supply. Where an oil heater is used on such a system it is necessary to have a return circulating main from the most distant point, with a similar discharge through a relief valve into the pump suction or the storage tank itself.

(4) Hand pumps of the rotary or semi-rotary type hardly need any comment, except that with very viscous oils the manual labour is apt to be quite considerable, and the normal pump capacity as compared with water very much reduced. They are useful, however, on small plants where the occasional filling of a gravity service tank is all that is required.

Pumping Calculations

This subject would be comparatively simple if it were not for the enormous number of variations in the same generic formula, which is quoted under many names and complicated further by each authority using a different set of units. In addition, the different types of viscometers with their confusing relationships make matters worse.

The author has a preference for the simplest one, *viz.*, D'Arcy's formula:—

$$h = \frac{4 f l v^2}{2 g d} \qquad (1)$$

with or without its somewhat crude appendage of the $\left\{1 + \frac{1}{12 d}\right\}$ as a correction factor for diameter.

This formula is comparatively simple in hydraulic problems where the variations of viscosity with temperature are ignored, and where nearly all pumping problems concern flow in turbulent motion with the square law for the velocity. One need therefore only remember a narrow limit for the friction factor ·005 to ·01 and the results per 100 ft. of pipe with different velocities of flow can be tabulated once and for all.

With oil the problem is distinctly more difficult, but it is definitely amenable to solution in a more accurate manner than with the comparatively crude correction factors of the D'Arcy water formula.

Exactly the same formula as (1) can be used, and it is only necessary to bear in mind that the frictional coefficient "f" can vary within very wide limits indeed.

Osborne Reynolds first established that this frictional coefficient is a function of the expression

$$\frac{d v \sigma}{\mu} \qquad (2)$$

where d is the diameter, v the velocity of flow, σ the density and μ the absolute viscosity in any self-consistent system of units. When $\frac{d v \sigma}{\mu}$ for any liquid or gas exceeds 2,500, flow is turbulent, and when below 2,000 it is sinuous or stream line, with an unstable condition between these two values.

It will generally be found in pumping problems with viscous oils that the flow is nearly always in the stream line region, but it is well to have the factors for both conditions. There are quite a number of tables published by different authorities connecting the coefficient "f" of equation (1) with the value of $\frac{d v \sigma}{\mu}$, but the author finds the one in "Handbook of the Petroleum Industry"—D. T. Day, Editor (John Wiley)—under the statement by Prof. Durand, the simplest to handle on account of its engineering units. A double logarithmic plot connecting "f" and $\frac{d v \sigma}{\mu}$ is given in Glazebrook's "Dictionary

of Physics" (Dr. Stanton's article on "Friction") and also in "Principles of Chemical Engineering," by Walker Lewis and Adams (McGraw Hill). A few short notes on units will be given later so that anyone who is so inclined may compare the results of the different authorities. The previously mentioned table by Prof. Durand is given below, with a slight conversion to agree with formula (1) since our authority uses a coefficient "f" including the 4 in our formula:—

$\frac{d\,v\,\sigma}{\mu}$	f	$\frac{d\,v\,\sigma}{\mu}$	f
100	·1600	1,200	·0133
200	·0800	1,400	·0114
400	·0400	1,600	·0100
600	·0267	1,800	·0089
800	·0200	2,000	·0080
1,000	·0160	2,400	·0067

The above represents stream line flow.

$\frac{d\,v\,\sigma}{\mu}$	f	$\frac{d\,v\,\sigma}{\mu}$	f
2,500	·0110	16,000	·0070
3,000	·0106	18,000	·0068
3,500	·0103	20,000	·0066
4,000	·0100	25,000	·0062
4,500	·0097	30,000	·0059
5,000	·0095	35,000	·0057
6,000	·0091	40,000	·0055
7,000	·0087	45,000	·0053
8,000	·0085	50,000	·0052
9,000	·0082	60,000	·0050
10,000	·0080	70,000	·0049
12,000	·0076	80,000	·0047
14,000	·0073	100,000	·0045

The above represents turbulent flow.

It will be seen how the coefficients used in hydraulic problems ranging from ·005 to ·01 fit into this table for turbulent flow.

The author has found that in certain cases of exceedingly viscous oil for low velocity flows, it is safe to exterpolate the above table with $\frac{d\,v\,\sigma}{\mu}$ well below 100, and the following factors then apply:—

$\frac{d\,v\,\sigma}{\mu}$	f
80	·20
60	·27
40	·40
20	·80
10	1·6

The possibility of high frictional coefficients of this order, amounting in the last case to 300 times that with water in turbulent flow, will indicate how unreliable it can be to guess some arbitrary multiple of the equivalent water friction as is sometimes done.

The chief difficulty in applying the above simple coefficients lies in the determination of the quantity $\frac{d\,v\,\sigma}{\mu}$ both in respect of the units used and the different methods by which viscosity is measured.

In the ft. lb. sec. units the relation between $\frac{\mu}{\sigma}$ and Redwood No. 1 viscosity is:—

$$\frac{\mu}{\sigma} = \cdot00000280\,t - \frac{\cdot00185}{t} \qquad (3)$$

where t is the time in seconds at the temperature involved, measured on the Redwood No. 1 instrument.

The above relation is sometimes expressed in poises, the C.G.S. unit for absolute viscosity, although a great deal of confusion is caused by the indiscriminate use of the word "poise" both for absolute and kinematic viscosity. This is due to the fact that "σ" the density in the C.G.S. system is approximately 1 for water and oil.

It must be clearly understood that the symbol "μ" is absolute viscosity having the dimensions

$$\frac{M}{L\,T};$$

the conversion factor from poises to ft. lb. sec. units is therefore

$$\frac{453\cdot6}{30\cdot5} \textit{ i.e.,}\ 14\cdot88.$$

The dimensions of kinematic viscosity $\left(\frac{\mu}{\sigma}\right)$ are obviously L^2, with a conversion factor from C.G.S. units to ft. lb. sec. units of 930. Multiplying the terms of equation (3) on the right-hand side by 930 we get

$$\frac{\mu}{\sigma}\ \text{(C.G.S. units)} = \cdot0026\,t - \frac{1\cdot715}{t} \qquad (4)$$

in which form this relation is sometimes given. It would be distinctly advantageous if all writers quoting results in different units would studiously avoid the use of the names "poise" or "centepoise" for kinematic viscosity.

The above outline still appears to make the problem of a simple

frictional calculation very complicated, but the subject becomes much simpler on direct numerical application.

As an example let us examine a simple case:—It is required to pump at the rate of 20 tons of oil per hour a distance of 3 miles. The maximum viscosity of the oil is 400 sec. Redwood No. 1, and the specific gravity 0·94. For what pressure should the pump be designed on a 3-in. pipe line?

The velocity "v" can be readily calculated as 4·34 ft. per sec. Substituting 400 for t in equation (3) we get

$$\frac{\mu}{\sigma} = \cdot 001115$$

Hence

$$\frac{d\,v\,\sigma}{\mu} = 793$$

From our table therefore $f = \cdot 0165$.

The loss of head in ft. on 3 miles of line is therefore:—

$$\frac{4 \times \cdot 0165 \times 15840 \times (4 \cdot 34)^2}{64 \cdot 4 \times \frac{1}{4}}$$

i.e., 1215 ft. (of oil S.G. 0·94).

The pressure necessary on the pumps is therefore 495 lb. per sq. in.

Even the above calculations can be considerably simplified where it is quite obvious that the flow is in the stream line region.

It will be observed from the table given that the following relation holds, approximately, up to the critical velocity, *viz.*:—

$$f \times \frac{d\,v\,\sigma}{\mu} = 16 \qquad (5).$$

Since, moreover, in formula (3) for values of "t" over 400 the second part of the expression on the right can be neglected compared to the first part, it simplifies to

$$\frac{\mu}{\sigma} = \cdot 00000280\ t.$$

Substituting in (5) we get

$$f = \frac{\cdot 0000448\ t}{d\,v} \qquad (6).$$

Equation (1) therefore becomes

$$h = \frac{\cdot 000002785\ 1\ v\,t}{d^2} \qquad (7).$$

or the loss of head in feet per 100 ft. is

$$H = \frac{\cdot 04\ v\,t}{D^2} \qquad (8).$$

where v is the velocity in feet per second,

t is the Redwood No. 1 viscosity in seconds,

and D is the diameter of the pipe in inches.

This formula (8) is therefore a very simple one to use for viscous flow when the Redwood No. 1 viscosity of the oil is given. It only applies, of course, where

$$\frac{d\,v\,\sigma}{\mu} \text{ is less than } 2{,}000.$$

If we use it in the example given previously, the error is insignificant, the result working out to 1,222 ft. instead of 1,215.

To eliminate all reference to absolute or kinematic viscosity the above criterion can be expressed as:—

$$\frac{12\,D\,v}{t} < 1 \qquad (9),$$

where D, v, and t are the same as in formula (8) and t is over 400 sec.

ZUSAMMENFASSUNG

Grade des Brennöls

Die Hauptmerkmale der verschiedenen Grade des Brennöls werden angegeben und besprochen. Es wird besonders auf die irreführende Klassifizierung nach dem spezifischen Gewicht, sowie auf die Notwendigkeit einer vorsichtigen Nomenklatur hingewiesen.

Lagerung

Sicherheitsmassregeln werden beschrieben und Empfehlungen für den Landgebrauch zusammengefasst. Es wird auch auf Lloyds Vorschriften zur See hingewiesen.

Bei Lagerbehältern werden unterschieden:

(1) Grosse zylindrische Stahlbehälter für Hauptlagerung in grossen Werken, mit Beschreibung der üblichen Ausrüstung.

(2) Behälter für kleinere Anlagen, mit Bemerkungen über die allgemeine Praxis. Betonbehälter werden erwähnt, und in die Erde eingelassene Behälter besprochen.

Fördern

Das Fördern wird in den folgenden vier Gruppen behandelt:

(1) Heizen: Die allgemeine Praxis bei grossen Lagerbehältern wird beschrieben, sowie kleine Leitungsheizer und Dampfheizer für Druckschmierapparate. Ungefähre Zahlenangaben für Wärmeübertragungsberechnungen und Wärmeverluste werden gemacht. Elektrische und Strahlungs-Wärmer werden beschrieben, mit Anmerkungen über die allgemeine Praxis.

(2) Reinigen und Trocknen: Vorsichtsmassregeln gegen Wasser und Schlamm werden behandelt, und handelsübliche Filter beschrieben. Zentrifugieren wird ebenfalls erwähnt.

(3) Verbindungen und Dichtungsmaterial: Einige allgemeine praktische Angaben werden über diesen Gegenstand gemacht, einschliesslich Pumpendichtungen und Massregeln zum Abdichten von Ölleitungen.

(4) Ölmessungen: Tauchbehälter, Wägen und Kalibrieren werden im allgemeinen besprochen und verglichen. Besondere Apparate wie Pneumerkator und Ölmeter werden behandelt.

Übertragung

(1) Pumpanlagen: Die führenden Typen werden unter den folgenden Überschriften allgemein besprochen:

(1) Dampfkolbenpumpen vom Einlinien- und vom "Duplex"-Typ.
(2) Ein-, Zwei- oder Dreizylinderkolbenpumpen (mit Riemen- oder Getriebeantrieb).
(3) Zwangsläufige Rotationspumpe.
(4) Rotierende oder halbrotierende Handpumpen.

Annäherungsformeln zur Berechnung des pro Tonne gepumpten Öls erforderlichen Dampfes.

(2) Pumpberechnungen: Mehrere bekannte Methoden werden eingehend besprochen und die Notwendigkeit des vorsichtigen Wählens der Einheiten wird hervorgehoben. Umrechnungen zwischen absoluten Einheiten und Viskosimeter-Ablesungen werden erwähnt. Es wird eine neue einfache Formel für zähflüssige Stromfäden entwickelt.

Der Gefällverlust in Fuss per 100 Fuss Rohrleitung wird bestimmt nach der Formel

$$H = \frac{0{,}04\, v\, t}{D^2}$$

mit den Kriterien $t > 400$ und $\frac{12\, D\, v}{t} < 1$

SHALE AND THE PRODUCTION OF OIL FROM SHALE

U.S. BUREAU OF MINES

HARRY H. HILL

*Paper No. F*11

CONTENTS

OIL SHALE RESOURCES OF THE UNITED STATES—CHARACTERISTICS OF AMERICAN OIL SHALE AND ITS PRODUCTS—COMMERCIAL OIL SHALE DEVELOPMENTS IN THE UNITED STATES—TECHNICAL AND ECONOMIC PROBLEMS OF OIL SHALE INDUSTRY—LABORATORY STUDIES OF U.S. BUREAU OF MINES—EXPERIMENTAL OIL SHALE PLANT OF U.S. BUREAU OF MINES (A) GENERAL AND HISTORICAL (B) DESCRIPTION (C) OPERATING RESULTS (D) FUTURE PROGRAMME OF WORK —RÉSUMÉ

Oil Shale Resources of the United States

The United States is fortunate in having, in its extensive deposits of oil shale, one of the largest potential sources of fuel in the world. These deposits should be considered as reserves of liquid fuel for, although some of the richer shales can be burned directly as fuel, it is unlikely that they will be utilised in that manner. The heating value of an oil shale yielding 42.7 gallons of oil a ton, which is considerably higher than the average oil yield from American shale, is only 4,400 B.Th.U. per pound; this is much less than that of a poor grade of coal. The ash content is high, usually above 60 per cent., which means that, if oil shale is used as a solid fuel, it would have to be burned near the source of production, as it would not be economical to transport a fuel containing such a high percentage of inert material. In view of these limitations, it is believed that oil shale will be retorted to furnish liquid products of high heating value which can be conveniently transported to consuming centres.

The oil shale deposits of the United States are widely distributed, commercial deposits existing in at least nine states—Colorado, Utah, Kentucky, Indiana, California, Wyoming, Montana, Nevada and Oregon. These shales vary in oil content from less than one gallon a ton for relatively thick beds to as much as 90 gallons a ton for extremely thin beds, the estimated average yield for a thickness of 500 feet in the Green River formation of Colorado amounting to approximately 15 gallons a ton. Winchester,[1] an authority on oil shale, has estimated that the oil shales and similar deposits in the United States contain 144,162,197,000 barrels (42 gallons each) of oil, of which 92,144,935,000 barrels can be recovered. This is more than one hundred times the production of crude petroleum in the United States for the year 1927, and seventy-four times the world production for that year. On the basis of heat units, this amount of shale oil is equivalent to 19,077,620,000 tons of bituminous coal, or thirty-seven times the United States' production of that fuel in 1927.

Characteristics of American Oil Shale and its Products

Little or no oil, as such, is found in typical American oil shales, but carbonaceous materials are present, which, by destructive distillation, yield oils. These oils differ in many respects from crude petroleum in that they contain much higher percentages of unsaturated hydrocarbons, a lower percentage of gasolene than the average crude oil, a higher percentage of wax, and a relatively high percentage of nitrogen compounds which have a rather offensive odour. An analysis of a typical shale oil from Colorada is as follows :—

Specific gravity, .901 (25.6° A.P.I.).
Sulphur, 0.53 per cent.
Nitrogen, 1.79 per cent.
Setting point, 26°C. (79°F.).
Unsaturation of tops, 39.1 per cent.

The crude shale oil has a fairly high heating value, about 18,400 B.Th.U. per pound, and, when distilled, yields fractions from which commercial products, such as gasolene, kerosene, lubricating oils, wax, etc., can be made by proper treatment. Owing to the high percentage of unsaturated compounds, it is

[1] Winchester, Dean E. *The Oil Possibilities of the Oil Shales of the United States*; Report II of the Federal Oil Conservation Board, January, 1928.

difficult to manufacture light products which remain water white upon standing, and it is questionable whether lubricating oils of high viscosity can be made from shale oil. The crude shale oil is an excellent fuel oil, although it sometimes contains relatively high percentages of sediment in the form of free carbon; since it is usually solid at temperatures below 60°F., it is often necessary to apply heat to make it flow to the burners. Doubtless, the best fuel oil from shale would be a product from a cracking distillation which had been topped to remove the more volatile fractions. Such a product would meet the requirements for flash point and would have a lower cold test than the original crude oil.

Although crude shale oil yields a relatively low percentage of gasolene and naphtha by straight distillation, it has been found that the yield of these products can be appreciably increased by subjecting the oil to a cracking distillation. The product thus obtained is difficult to treat for colour and odour, but experiments indicate that, unlike the cracked products from crude petroleum, those obtained by cracking shale oil can be treated as easily as ordinary straight run distillates.

Commercial Oil Shale Developments in the United States

A few years ago, when there was a threatened shortage of petroleum, an immense amount of interest was taken in the development of the oil shale deposits of the United States. Several thousand acres of oil shale land were leased or purchased, and at one time more than 100 oil shale companies were in existence. Many of these companies built small plants, but a number of them simply purchased oil shale lands and sold stock to the public. All of the plants which were built were too small to be considered of commercial size, but mostly they represented experimental plants for developing and testing new types of retorts. A plant of semi-commercial size was operated in Nevada for a few years and marketed oil shale products both in this country and abroad. Another was operated in California for some time and produced an oil that was marketed as fuel oil. These plants are the only two which can be considered as approaching commercial operation. At the present time none of the plants owned by oil shale companies is in continuous operation, and only two or three are operated intermittently. Owing to the overproduction of crude petroleum in the United States and consequent low prices, the interest in oil shale has lessened to a

considerable extent, although some of the larger oil companies have increased their oil shale holdings during the past three years.

Technical and Economic Problems of Oil Shale Industry

It is generally recognised that many problems of a technical and economic nature must be solved before an oil shale industry can be established in the United States on a profitable basis. In the mining of oil shale it must be determined whether selective mining should be employed, and only the richer material utilised, or whether the entire deposit should be mined by some system such as the caving method, or by stripping and using open-cut methods. At one time it was considered advisable to use somewhat similar methods to those employed in the mining of coal, but many mining engineers are now of the opinion that it would be better to adopt methods similar to those used in mining low-grade copper ores, and mine all the oil-bearing shale for a thickness of perhaps 200 to 500 feet. This method would, no doubt, result in a lower cost per ton, but the oil yield per ton would be appreciably lower.

It will be necessary to make an exhaustive study of retorting conditions before a successful method for retorting American shales can be developed. The Pumpherston retort, which has been used in Scotland for more than twenty-five years, produces a good grade of oil from American shales, but its throughput is low and it requires large quantities of water in the form of steam. Some of the American retorts have much larger capacities, but none of them has been operated for sufficient time, or on a wide enough variety of shales, to determine definitely whether it will prove satisfactory under different operating conditions. Work of a fundamental character is necessary to determine the factors which must be considered in designing retorts for operating on American shales.

Since shale oil is entirely different from crude petroleum it is probable that new methods of refining will have to be developed, as it is unlikely that the methods used for refining petroleum will prove entirely satisfactory. It will also be necessary to determine the products which can be manufactured most profitably, for it is questionable whether shale oil will yield the same range of products now made from petroleum.

It will also be necessary to consider such problems as the transportation of shale oil or refined products, water supply, disposal of waste products, labour problems, etc. The richest and most

extensive oil shale deposits in the United States are in sparsely settled sections of the country, where transportation costs are high and the market for petroleum products is limited. In these sections the rainfall is sparse and most of the water is required for agricultural purposes. It would be difficult, therefore, to obtain sufficient water for the refining of shale oil, even if a retort were used requiring no water. Again, the disposal of spent shale is a problem of major importance in the Western States, as the valleys between the oil shale deposits are usually quite narrow and the river bottoms valuable for agriculture. The housing and welfare of the large labour force needed would also require consideration.

Laboratory Studies of U.S. Bureau of Mines

Realising that information on the chemical and physical properties of oil shale and shale oil would be required before an oil shale industry could be started in the United States, the Bureau of Mines began a series of laboratory studies about eight years ago. These investigations included the determination of such properties as specific gravity, specific heat, heat of combustion, and thermal conductivity of the different types of American shales, the analysis of oil-shale ash, the determination of sulphur and nitrogen, and the development of a standard method for assaying samples of oil shale to determine the yield of oil. Studies were made of the effect on the yield and quality of oil, of retorting conditions, such as rate of heating, introduction of steam or other gases and size of shale retorted. Analytical distillations were made of the shale oils produced and special attention was paid to methods of treating the distillation products. The investigations also included studies of the coking properties of oil shale and the determination of the explosibility of oil shale dusts.

EXPERIMENTAL OIL SHALE PLANT OF U.S. BUREAU OF MINES

General and Historical

Although the laboratory investigations furnished valuable information on the problems which must be considered in producing oil from American shales, it became evident that before some of the problems could be studied it would be necessary to conduct experiments with large scale equipment. It was not considered advisable to ship large quantities of oil shale to Scotland to be tested in the retorting plants there, for it was realised that it

would be necessary to study a number of conditions peculiar to the Western States, where the largest and richest deposits are found. An appropriation was, therefore, requested for the erection of an experimental oil shale plant in Western Colorado. The first appropriation of $90,000 became available on March 3, 1925, and this was followed by a second appropriation of $89,000, which was for the purpose of operating the plant until June 30, 1927. The plant was shut down on that date, owing to the failure of Congress to provide funds for its continued operation, but in December, 1927, a fund of $45,000 was voted for reopening the plant; this was followed by a later appropriation of $75,000 for operating the plant during the fiscal year beginning July 1, 1928. After a number of changes had been made to the plant, including the conversion of the tramway to a two-bucket system, operations were resumed on June 21 of this year.

DESCRIPTION

The experimental oil shale plant of the Bureau of Mines is located on Naval Oil Shale Reserve No. 3, near Rulison, Colo. The plant consists of two retorts, one a standard Pumpherston experimental retort of full commercial size and of the type used in Scotland for the last twenty-five years, the other, a retort of American design known as the N-T-U, two 35-H.P. boilers, a 40-H.P. gas producer, an oil-shale crusher, pipe still, storage tanks, etc. A 5,600-ft. aerial tramway is used for transporting the shale from the mine to the retorting plant.

The retorts were selected on the basis of information gained in the laboratory studies supplemented by a field study of the retorts proposed or in use in the United States and other countries. Both types are well adapted for experimental studies and have been operated for a period long enough to establish their advantages and limitations. The Pumpherston retort is a continuously operating, externally heated retort, using fairly large quantities of steam, while the N-T-U is internally heated, intermittently operating, and does not make use of steam. The N-T-U retort has a charging capacity of about 25 tons, while the capacity of the Pumpherston retort is determined, to a large extent, by the quality of shale retorted. For a period of five consecutive days the throughput of the Pumpherston retort at the experimental plant exceeded 7.5 tons a day of 29-gallon shale, and on two days the throughput was more than 8 tons a day, but its average daily capacity is considered to be about 5 tons of fairly rich shale. The

two retorts form a good combination for experimental study, in that the Pumpherston retort exemplifies slow distillation and the N-T-U retort rapid distillation.

Operating Results

The Pumpherston retort produces oils which are somewhat lighter and contain higher percentages of the more volatile fractions than those produced by the N-T-U retort, but, otherwise, the oils from the two retorts are similar. The oil produced by the Pumpherston retort has an average specific gravity of about .887 (28° A.P.I.) and yields an average of about 15 per cent. of gasolene and naphtha. The oil from the N-T-U retort has an average specific gravity of about .928 (21° A.P.I.) and has a gasolene-naphtha content of about 8 per cent. The gasolene-naphtha fraction from both crudes is deficient in low boiling fractions, and it will be necessary to blend the product with more volatile material in order to produce a finished motor fuel. Experiments have shown that as much as 60 per cent. of motor fuel can be made from shale oil by cracking. Analyses of typical samples of oil from the two retorts are given in Table 1.

During the operating period which ended on June 30, 1927, a total of 2,129 tons of oil shale was run through the retorts, yielding 37,909 gallons (903 barrels) of oil, an average yield of 17.8 gallons a ton. The shale charged to the retorts had an oil content ranging from 11 to 43 gallons a ton, the highest average yield for a single day's operation amounting to 42.5 gallons a ton. The oil shale used in the plant was mined in a quarry at the outcrop of the shale on the escarpment at an elevation of about 2,400 feet above the plant site. A thickness of approximately 60 feet of the shale escarpment was mined, which included the rich "mahogany ledge."

As a result of nine months' operation of the experimental oil shale plant, valuable information was obtained on the problems of producing oil from American shales. Data were secured on drilling and shooting oil shale, on retorting methods to be followed in order to obtain the highest yield of the best quality of oil and on refinery methods offering promise of good results in the manufacture of refined products. It was found, for example, that both retorts operated satisfactorily on the non-coking shales, but both gave trouble when handling shales of the coking variety. Several "hang-ups" occurred in the Pumpherston retort, but

TABLE I.

	Oil from Pumpherston Retort				Oil from N-T-U Retort			
Specific Gravity	0·890				0·920			
A.P.I. Gravity	27·5°				22·3			
Sulphur	0·66%				0·85%			
Pour Point	55°F.				75°F.			
Saybolt Universal Viscosity at 70°F.	65 Seconds				Solid			
Saybolt Universal Viscosity at 100°F....	47 Seconds				112 Seconds			
	Per cent.	S. G.	°A.P.I.	Viscosity	Per cent.	S. G.	°A.P.I.	Viscosity
Gasolene and Naphtha ...	15·9	0·793	46·9		8·5	0·804	44·5	
Kerosene Distillate ...	—	—	—		—	—	—	
Gas Oil	30·1	0·862	32·7		23·1	0·866	31·9	
Non-viscous Lubricating Distillate ...	17·1	0·892–0·922	27·1–22·0	50–100	10·7	0·896–0·923	26·4–21·8	50–100
Medium Lubricating Distillate ...	Indeterminate			100–200	8·7	0·926–0·933	21·8–20·2	100–200
Viscous Lubricating Distillate ...	Indeterminate			Above 200	11·3	0·933–0·939	20·2–19·2	Above 20(
Residuum	10·9	0·987	11·9		36·9	0·997	10·4	
Carbon Residue of Residuum	7·1				7·1			
Carbon Residue of Crude	0·8				2·6			

these may have been due partly to the leakage of air and combustion products through a crack in the inner wall of the retort. This crack was discovered when the retort was shut down and has since been repaired. Gas circulation practically ceased when coking shales were charged to the N-T-U retort, but this difficulty can be overcome by the use of an exhauster of larger capacity; this is now being installed. The Pumpherston retort gave a high recovery of a good grade of shale oil, and when operating on the richer shales was practically self-supporting as regards fuel for heating the retort, the gas produced during retorting being used for that purpose. The average recovery of oil from the N-T-U retort was not quite so high as from the Pumpherston, nor was the oil of such high quality; the capacity of the N-T-U retort is, however, much higher, and it has the advantage of not requiring any additional fuel. Sufficient data are not available to determine which type of retort is best adapted to American shales, but on the basis of experience gained during the time the plant was operated it was decided slightly to modify both retorts before resuming operations.[2]

PROGRAMME

During the coming year it is hoped to secure additional information on such retorting problems as the effect of rate of heating, variations in amount of steam used, size of shale retorted, heat transfer, recirculation of retort gases and the determination of the maximum percentage of coking shale that can be satisfactorily retorted. Special studies will be made of conditions favourable to the production of ammonia and to the formation of sufficient gas to make the Pumpherston retort self-supporting.

The work on refining problems will be continued, but for the present particular attention will be paid to the production of motor fuel by cracking and to the development of methods for treating it. Future work will include studies of the manufacture of lubricating oils and other products from shale oil.

RÉSUMÉ

En considérant les approvisionements futurs de combustibles liquides, il ne faut pas oublier les gisements de schistes bitumineux aux Etats-Unis. On

[2] A comprehensive report, giving the results of nine months' operation of the experimental plant, is being prepared, and will be published as a Bureau of Mines bulletin. An article by Martin J. Gavin, entitled "The Bureau of Mines Experimental Oil Shale Plant," will be published in the August, 1928, issue of the *Journal of Industrial and Engineering Chemistry*. This article gives a description of the plant and discusses some of the results obtained.

estime qu'il sera possible de récupérer à peu près quatre-vingt-douze millions de barils d'huile de ces gisements. Il s'agit de plus de cent fois la production de pétrole brut aux Etats-Unis pour l'an 1927, et soixante-quatre fois la production mondiale de cette année.

La teneur en huile des schistes varie de moins d'un gallon par tonne jusqu'à quatre-vingt-dix gallons par tonne, la moyenne des gisements les plus grands étant à peu près de quinze gallons par tonne. L'huile récupérée est d'ordinaire une huile moyennement lourde contenant des teneurs élevées en cire et en hydrocarbures insaturés. L'analyse d'une huile de schiste typique provenant du Colorado donne le résultat suivant:

Poids spécifique	0,901 (25,6° A.P.I.)
Soufre	0,53 pour cent.
Point de faire prise	26°C. (79°F.)
Insaturation des premières parties	39,1 pour cent.
Valeur calorifique	10,200 calories par gramme (18.360 B.Th.U. par livre).

On peut faire des produits raffinés, tels que l'essence, le kerosène, et des huiles à graisser en partant de la huile de schiste, mais il faut des méthodes spéciales d'épuration.

Beaucoup de compagnies ont été organisées aux Etats-Unis pour exploiter l'huile de schiste, plusieurs milles acres de terre contenant du schiste bitumineux ont été pris à bail ou achetés et plusieurs petites usines à distillation ont été construites. A présent, cependant, aucune usine possédée par une compagnie d'exploitation d'huile de schiste n'est en marche continue, et deux ou trois seulement sont exploitées d'une façon intermittente. Aucun des ateliers construits n'a été de grandeur industrielle, mais dans la plupart des cas ils ont représenté des usines expérimentales pour développer et essayer des types nouveaux de cornues.

Il faudra résoudre beaucoup de problèmes de nature technique et économique avant qu'il sera possible d'établir une industrie de l'huile de schiste aux Etats-Unis à base rémunératrice. Il faudra développer des méthodes d'exploiter le schiste à un prix de revient réduit et de le livrer à l'atelier de distillation avec des frais de transport minima. Il faudra développer des vases clos qui seront capables de produire des débits maxima de la meilleure huile avec une consommation minimum de houille et d'eau. Il faudra modifier les méthodes d'épuration ou développer des méthodes nouvelles pour produire des produits vendables, partant d'une huile qui diffère beaucoup du pétrole brut. Enfin, il faudra accoutumer le public consommateur à accepter des produits tirés de l'huile de schiste à la place de ceux tirés du pétrole.

Le Bureau des Mines des Etats-Unis exploite une usine expérimentale d'huile de schiste dans le Colorado occidental dans le but d'étudier quelques-uns des problèmes qui se présentent à l'industrie de l'huile de schiste. On étudie deux types de vases clos, la cornue Pumpherston que l'on a employée en Ecosse pendant plusieurs années et un typ de cornue américain de construction bien différente. Plus de 2.000 tonnes de schiste on été distillées dans cette usine, ayant donné à peu près 900 barils d'huile de schiste. Plusieurs laboratories sont en train de faire l'étude du raffinage de cette huile et les résultats seront puliés plus tard par le Bureau des Mines. Grâce au travail de l'atelier expérimental on a obtenu des indications précieuses sur le problème de la distillation des schistes américains et du raffinage de l'huile de schiste.

THE CRACKING PROCESS—A UNIVERSAL SOURCE OF MOTOR FUEL

AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS

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INTRODUCTION

(*a*) Crude Oil Resources

The total amount of crude oil in the earth's crust is unknown, and unestimated, but it is certainly an astonishing volume. Geologists state that oil discovery is a possibility in 1,100,000,000 acres in the United States alone, or 56 per cent. of its total land area. The contrast of this huge territory with the 2,000,000 acres producing oil at the present time, makes it certain that new fields will be continually discovered and that the oil of that country will prove ample for many years to come. What is true regarding the potential oil production of the United States is probably true in even greater measure for many of the other countries of the world where oil exploration has been even less thorough than in the United States.

From the beginning of production on a significant scale in the year 1857 to the end of 1927, the oil fields of the world produced 16,000,000,000 barrels of petroleum. This is, however, only a fraction of the oil resources of the producing areas, for it is estimated that at the most, 20 per cent. of the oil in the ground is brought to the surface by present methods of recovery. For every barrel of oil produced at least four barrels remain in the

earth. While 16,000,000,000 barrels of oil have been produced, 64,000,000,000 barrels or more are still in the oil sands. This oil alone, could it be recovered by means of flooding, repressuring or mining, would supply the world's needs for over fifty years.

Since the foundation of the petroleum industry, many predictions of oil shortage have been made. But despite the stupendous increase in the use of petroleum during the last two decades, discovery of new fields has never failed to keep pace with the demand. At the present time the world's output of oil is far below the capacity of the actual producing wells. Proration and drilling agreements are holding back a veritable flood of crude, which could be produced in amounts far exceeding present requirements. In view of the known crude oil reserves, the vast amount left underground by present production methods, and the undiscovered fields that no doubt exist, an oil shortage, despite the gloomy prophets, is far in the future.

It may not be too optimistic to predict, considering past and present experience throughout the world, that crude oil will be our dominant source of gasoline for at least a century to come.

(*b*) The Development and Magnitude of the Cracking Process

The commercial cracking of heavy oils into gasoline, is of comparatively recent development. There are few refiners of crude oil who can operate economically without the cracking process as part of their regular equipment. The automobile industry could scarcely have developed to its present size were it not for the supply of gasoline made available by cracking, as otherwise the price of motor fuel would be distinctly higher than it now is.

Vast amounts of money have been expended in research on cracking in working out the commercial conversion of fuel oils into gasoline. It is estimated that over $40,000,000 has been spent in endeavours to develop commercial cracking processes.

The improvement which has been made in cracking units in their evolution during the last two decades or so, has been startling. The early shell cracking stills, some of which are still in use, had a daily capacity of approximately 125 barrels each. They were limited to the use of a selected gas oil charging stock, and their yield of gasoline was about 30 per cent. The modern cracking process employs units having a capacity of 750 to over 2,500 barrels per day, converting any type of oil—kerosene distillate, gas oil, fuel oil, topped crude, or crude oil—into gasoline with yields of 50 to over 75 per cent. Despite the somewhat greater complexity of the

modern pressure still, its high efficiency makes the first cost, per barrel of gasoline produced per day, only one fourth of that of the early cracking units. Had it not been for the great advance in the process of cracking, the investment necessary to produce the present volume of cracked gasoline would be over $1,000,000,000, instead of the $275,000,000 which is the approximate value of the world's present cracking equipment and its auxiliaries, such as storage tanks, agitators, rerun stills, boiler houses, land, etc.

The use of the cracking process is world wide. Commercial plants are now in operation or under construction in such widely separated countries as Japan, Borneo, Java, the Dutch East Indies generally, Australia, Roumania, India, Great Britain, Belgium, Italy, Argentina, Trinidad and Canada, as well as in all the refining areas of the United States.

In the United States 148 of the 312 operating refineries are equipped with cracking units. These are the largest and most modern of the refineries. The remaining 164 without cracking equipment have only 23 per cent. of that country's capacity for handling crude oil. The total cracking capacity is 1,328,000 barrels of charging stock per day. In 1927, the United States refineries produced 101,000,000 barrels, or 4,200,000,000 gallons of cracked gasoline, which was 30·6 per cent. of the total motor fuel, as shown in the table following:

PRODUCTION OF GASOLINE IN UNITED STATES[1]
(Thousands of Barrels).

	1927.		1926.		1925.	
	Total.	per cent.	Total.	per cent.	Total.	per cent.
Total gasoline production	330,667	—	299,734	—	259,601	—
Straight run gasoline	197,282	59·7	178,302	59·5	171,382	66·0
Cracked gasoline ...	101,224	30·6	93,736	31·3	68,583	26·4
Natural gasoline ...	32,161	9·7	27,696	9·2	19,636	7·6

The daily capacity of the cracking units in the other countries is estimated to be approximately 65,000 barrels.

(*c*) The Cracking Process as a National Necessity

The cracking of oil is not only a matter of great interest to countries with supplies of petroleum, but it is a subject of national import to every land. To the oil producing countries the installation of cracking equipment is a necessity for the most economical use of their oil resources. The modern cracking process is of such

[1] Oil Gas Jour., March 1, 1928, p. 120

general application that those nations not possessing petroleum, but having oil shale or coal, may well make use of cracking to produce gasoline from oil secured by the retorting of these materials. These countries, as well as those possessing no deposits of hydrocarbon material, may purchase fuel oil, available at reasonable prices at every port in the world, and crack it into at least 50 per cent. of gasoline.

In peace time cracking plants should prove profitable in any part of the world; in times of stress they are an important element of national defence. The use of aeroplanes and the mechanisation of armies has made an abundant supply of gasoline a necessity to national security.

National interest requires, particularly in time of stress, that the greatest possible amount of gasoline be secured from every oil resource. The cracking process yields more than double the gasoline obtainable by simple distillation of crude oil, coal tar, or shale oil. Installation of the cracking process is therefore supremely important to every country possessing petroleum, coal, or shale. Lacking these resources, prudence would suggest that a nation provide sufficient stores of motor fuel to cover any emergency. Far better than storing gasoline would be the provision of cracking equipment and the construction of huge reservoirs for fuel oil storage. Fuel oil is relatively low in price, does not deteriorate or evaporate, and is not dangerously inflammable. It may be cracked as required to give high yields of gasoline. Concrete reservoirs of 1,000,000 barrels or greater capacity, built underground and in sufficient number to supply a nation's needs for a term of years, are entirely feasible. A country of the size of France, for example, which consumes in the neighbourhood of 400,000,000 gallons of gasoline per year could accumulate, over a period of time, 100,000,000 barrels of fuel oil. This would furnish, by cracking, 50,000,000 barrels, or 2,100,000,000 gallons of gasoline, sufficient for 31,500,000,000 car miles—a five year peace time supply and probably sufficient for the requirements of national defence. A country like Italy, whose annual gasoline utilisation is about 48,000,000 gallons, should store perhaps 20,000,000 barrels of fuel oil, which would supply 10,000,000 barrels or 420,000,000 gallons of gasoline. This is equivalent to 6,300,000,000 motor car miles.

That storage of this volume of fuel oil is entirely possible is evident from the fact that amounts of petroleum vastly greater than those mentioned are continually in storage in America. The stored oil in the United States at the present time amounts to approximately 600,000,000 barrels.[1]

[1] Amer. Petroleum Institute, 9, No. 35, p. 3, June 6, 1928.

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Country.	Crude Oil Production 1927, in bbls.[1]	Motor Vehicle[2] Registration Jan. 1, 1928.	Population[2] per motor vehicle.	Gasoline Consumption in gallons.		Retail Prices, Dec. 31, 1927. Cents per gallon.		Prices of Fuel Oil at nearest port, in cents per per gallon.[5]
				per car[3] 1923-4.	total estimated 1927.	Gasoline.	Kerosene.[4]	
Argentine ...	8,700,000	241,356	42	532	128,800,000	38	32	5·4 Buenos Aires
Australia ...	—	423,521	14	185	78,000,000	42	30	6·4 Adelaide
								6·4 Brisbane
								6·2 Melbourne
								6·4 Sydney
Austria ...	—	24,800	270	427	10,600,000	25	16	6·2 Trieste, Italy
Belgium ...	—	100,000	79	414	41,400,000	30	19	6·3 Rotterdam, Holland
Bolivia ...	—	1,985	1,310	269	534,000	58	50	5·3 Iquique, Chile
Brazil	—	136,000	264	497	67,500,000	39	40	6·3 Rio de Janeiro
								6·2 Pernambuco
								6·4 Santos
Bulgaria ...	—	2,265	2,450	—	—	36	25	6·0 Piræus, Greece
Canada ...	495,000	939,478	10	434	400,800,000	21	22	4·4 Montreal
								4·6 Quebec
								3·1 Vancouver
Ceylon ...	—	13,812	363	264	3,650,000	45	40	6·2 Colombo
Chile	—	19,271	203	369	7,120,000	39	35	5·3 Antofogasta
								5·3 Iquique
								4·9 Valparaiso
China	—	22,188	19,700	568	12,600,000	43	25	7·5 Ichang
								6·2 Hankow
								5·8 Hongkong
								5·8 Shanghai
Colombia ...	15,000,000	11,291	622	500	5,646,000	70	59	3·4 Balboa, C.Z.
Cuba	—	45,000	79	781	35,150,000	25	—	4·3 Havana
Czechoslovakia	140,000	39,950	354	—	—	31	19	6·2 Trieste, Italy
Denmark ...	—	83,900	41	522	43,800,000	27	22	7·8 Stockholm, Sweden (Diesel Oil)
Dutch E.I. ...	21,400,000	44,394	1,180	461	20,450,000	40 (Java)	30	5·8 All ports
Ecuador ...	450, 000	1,457	1,370	611	890,000	52	46	3·4 Balboa, C.Z.
Egypt	1,235,000	21,890	650	196	4,290,000	31	17	6·2 Alexandria
								6·2 Port Said
								6·6 Suez
Esthonia ...	—	2,603	698	—	—	29	—	7·8 Stockholm, Sweden (Diesel Oil)
Finland ...	—	25,101	140	—	—	29	17	7·8 Do. do.
France... ...	480,000	956,000	40	439	420,000,000	32	23	6·2 Marseilles
								6·2 Havre
								6·2 Rouen
								6·4 St. Nazaire
Germany ...	600,000	422,300	148	125	52,600,000	28	19	5·8 Hamburg
Greece ...	—	13,885	492	—	—	42	51	6·0 Piræus
Guatemala ...	—	2,473	1,200	—	—	70	56	3·4 Colon, C.Z.
Holland ...	—	73,894	120	438	32,400,000	23	21	6·3 All ports
Honduras ...	—	469	1,648	—	—	62	85	3·4 Colon, C.Z.
Hungary ...	—	13,097	648	—	—	29	25	6·2 Trieste, Italy
India	8,200,000	117,000	2,730	311	26,400,000	30	—	6·2 All ports
Irish Free State	—	36,763	810	—	—	25	19	6·2 All English ports
Italy	52,000	158,600	254	302	47,700,000	53	46	6·2 All ports
Japan	1,700,000	54,654	1,525	734	40,100,000	32	30	5·8 All ports
Lithuania ...	—	1,201	1,690	—	—	28	20	7·8 Stockholm, Sweden (Diesel Oil)
Morocco ...	—	13,798	248	797	11,080,000	39	29	6·2 Gibraltar
Mexico ...	64,120,000	57,139	272	1,030	58,800,000	33	42	3·7 Puerto, Mexico
								3·1 Tampico
								3·1 Vera Cruz
								3·7 Tuxpan
New Zealand ...	—	134,215	10	339	45,500,000	—	—	6·4 Wellington
Nicaragua ...	—	493	1,325	—	—	44	40	3·4 Colon, C.Z.
Norway ...	—	34,170	81	464	15,900,000	—	—	7·8 Oslo (Diesel Oil)
Panama ...	—	4,584	109	—	—	30	26	3·4 Colon, C.Z.
Paraguay ...	—	1,018	1,000	541	562,000	—	—	5·4 Buenos Aires, Argentina
Persia	39,200,000	6,560	1,520	—	—	68	—	6·2 Bombay, India
Peru	10,000,000	10,525	520	651	6,850,000	31	24	5·3 Iquique, Chile
Philippine Is....	—	28,810	407	508	14,650,000	36	23	5·8 Cebu
								5·8 Lloilo
								6·2 Manila
Poland ...	5,300,000	21,850	1,340	496	10,850,000	32	26	7·8 Stockholm, Sweden (Diesel Oil)
Roumania ...	26,300,000	22,200	775	307	6,810,000	22	10	6·0 Piræus, Greece
Russia ...	72,400,000	21,000	690	982	20,600,000	—	—	7·8 Stockholm, Sweden (Diesel Oil)
Siam	—	6,672	1,460	204	1,360,000	43	29	5·8 Bangkok
Spain	—	176,675	125	450	79,200,000	43	36	6·2 Lisbon
Sweden ...	—	108,800	55	547	59,900,000	34	33	7·8 Stockholm (Diesel Oil)
Switzerland ...	—	50,265	78	404	20,300,000	53	29	6·2 Genoa, Italy
Turkey ...	—	7,000	1,908	—	—	36	42	6·0 Piræus, Greece
Trinidad ...	5,380,000	3,918	78	—	—	—	—	—
UnitedKingdom	—	1,173,000	37	434	508,000,000	24	24	5·8 All ports
United States ..	903,800,000	23,127,315	5	541	12,512,976,000	—	—	3·2 New York
								2·7 San Francisco
Uruguay ...	—	34,575	49	356	12,330,000	32	40	5·7 Montevideo
Venezuela ...	64,400,000	15,004	197	395	5,950,000	34	34	3·3 Trinidad
Yugoslavia ...	—	10,480	1,146	—	—	47	47	6·2 Trieste, Italy

[1] Amer. Petroleum Inst., IX No. 14, Feb. 29, 1928.
[2] Figures from U.S. Department of Commerce.
[3] World Trade in Gasoline. U.S. Department of Commerce, 1925.
[4] Special Circular No. 653, Minerals Division U.S. Department of Commerce, 1928.
[5] Fairplay, January 5, 1928, p. 73.

Interesting light on this proposal is afforded by a study of the following table, which shows for the principal countries of the world, the crude oil production, motor car use, gasoline consumption, gasoline and kerosene prices, and an approximation of the prices at which fuel oil can be obtained. In large quantities, the cost of fuel oil would probably be considerably less than the figures given.

(*d*) Conservation of Crude Oil due to Cracking

The cracking process is the most effective force in oil conservation. Owing to the fact that one-third of our gasoline is made by cracking instead of by the simple distillation of crude oil, it is necessary to produce far less petroleum than would be required were the cracking process not in use. During the year 1927, 450,000,000 barrels of crude oil were conserved by the cracking process which produced 4,500,000,000 gallons of gasoline from oils which contained no gasoline as such. Without the agency of the cracking process the oil fields of the world would have been called upon for 1,700,000,000 barrels of oil during the year 1927, instead of the 1,255,000,000 actually produced, which was sufficient (in fact more than sufficient) to supply the requirements of the world's 29,500,000 automotive vehicles. During the last 15 years the saving in crude oil due to the cracking process is conservatively estimated at over 1,750,000,000 barrels.

Had all the gasoline of recent years been produced by simple distillation of crude oil, vast quantities of fuel oil would have been thrown on the market, probably depressing it considerably and bringing the oil into greater competition with coal. It is far more fitting, as a national policy, to utilise fuel oil for gasoline making, which may be termed the higher use, than to burn it under boilers.

THE CRACKING OF PETROLEUM OILS

(*a*) The Flexibility of the Cracking Process

The primary use of the cracking process at the present time is the conversion of petroleum into gasoline and other products. No one method of operation will fit all the economic demands made upon the refining industry. Of necessity, therefore, the process must be so flexible that oil of any type can be cracked into the products in greatest demand. This condition is fulfilled by the modern cracking process, the adaptability of which is such that it may be operated for maximum yields of gasoline, furnace or Diesel oil, residual oil having a higher B.Th.U. content per barrel than the original charging stock, coke or gas. Viscous oils may be used as

charging stock and lightly cracked in order to lower their viscosity and cold test so that they will flow readily through pipe lines. The manner in which the process is used depends upon market conditions and the oil available for cracking. The change from operating for a given product to producing another product in maximum yield, is made without modification of the cracking unit in principle or equipment.

(*b*) The Residual Oil Type of Cracking Operation

Residual oil type operation permits the production of high yields of gasoline, furnace or Diesel oil and a minimum amount of coke and gas, while the residual fuel oil has a higher thermal value per barrel than the original charging stock.

The operation of the cracking process will best be understood by a description following the flow chart of a typical installation.

The oil to be cracked is pumped to the plant at a uniform rate by pump *A*, the suction side of which is connected to the oil storage tank. The raw charging stock may be pumped into the flash condenser *C*, to the dephlegmator *H*, or directly to the heating tubes *I*. All the charging stock may be pumped to any one of these elements of the cracking system, or it may be split as the operating conditions warrant. The charging stock pumped into the flash condenser *C* comes into intimate contact with the vapours from the flash chamber *Q*, so that the temperature of the charging oil is raised by condensing a portion of the vapours. The charging stock and condensed vapours are drawn from the bottom of the flash condenser *C* by the hot oil pump *D* and discharged into the dephlegmator *H* by means of the pipe connection *G*. The preheated charging stock comes into contact with the hot vapours in the dephlegmator, and is thereby raised to a substantially higher temperature. As an alternative, part or all of the charging stock and condensed vapours from the flash condenser may go directly through the feed line *E* to the heating tubes *I*. The valves *OO* control the proportion of the split feed which passes to the heating coil *I* or to the dephlegmator *H*. The feed oil enters the heating coil at a temperature of approximately 385°C. (725°F.), and passes through the heating tubes, which are connected by return bend fittings to form a continuous coil. The oil is heated by the gases generated in the combustion chamber *L*, attaining a cracking temperature of 460°C. (860°F.), more or less. The products of combustion pass through port holes in the upper part of a wall which divides the furnace into two chambers, and come in contact with the heating

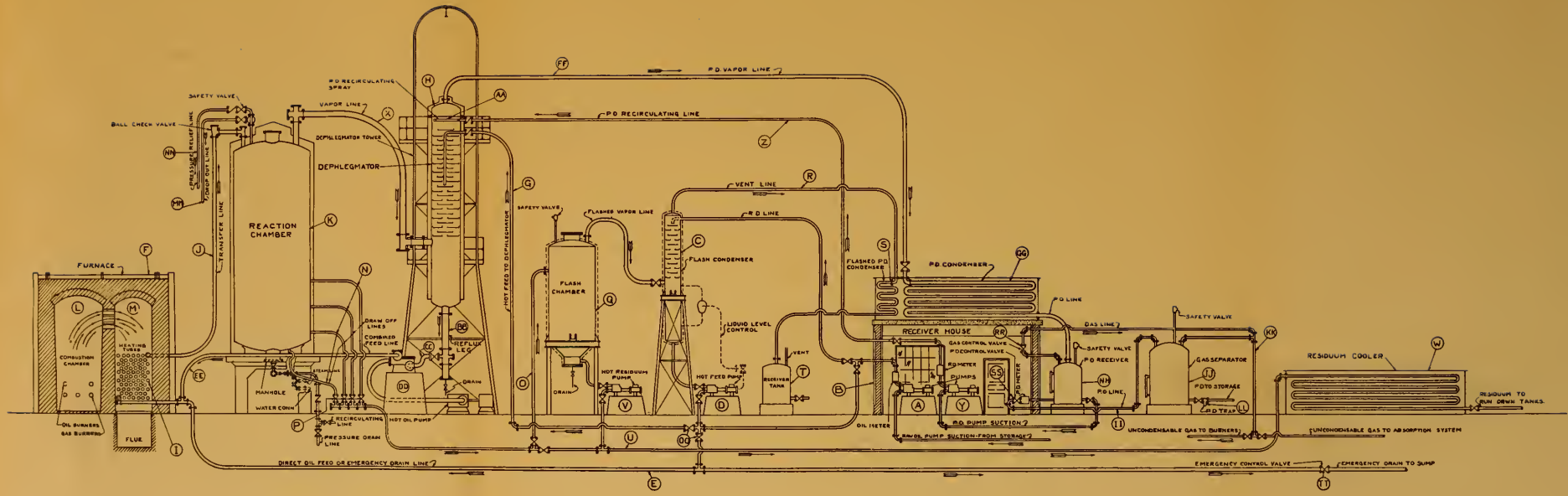

FIG.—To face p. 768

coil in chamber *M*. The combustion gases flow counter to the direction of the oil in the heating tubes, and the spent gases pass through a flue to the stack. The heated oil leaves the last tube of the coil and discharges from the transfer line *J*, into the reaction chamber *K*. The reaction chamber is not fired or heated externally and is thoroughly insulated against heat losses.

The residual oil is withdrawn from the lower portion of the reaction chamber *K* through the draw-off pipe connections *N* by means of control valves *P*. It then passes through line *O* into the flash chamber *Q*, which is maintained under a pressure lower than that of the reaction chamber *K*. Here the lighter portions are flashed off as vapours, leaving a heavy residuum to be drawn off from the bottom of the flash chamber. The vapours pass from the chamber *Q* to the flash condenser *C*, where they are brought into contact with fresh charging stock to which they give up a portion of their heat, and where they in part undergo condensation. The uncondensed vapours pass through the line *R* to the cooling coil *S* and are collected in the receiver *T*. The hot residual oil from chamber *Q* may pass through the cooling coil *W* to a storage tank, or it may be burned in the combustion chamber *L* while still in a heated condition.

The cracked vapours leave the top of the reaction chamber *K* through the vapour line *X*, which is connected to the dephlegmator *H*, where they mingle with the ingoing preheated cracking stock.

The temperature of the vapours leaving the dephlegmator *H* is maintained at any point desired by cooling with pressure distillate oil. This cooling is accomplished by means of a pump *Y*, which discharges a portion of the pressure distillate drawn from the receiver *HH* into the recirculating line *Z*, the oil then entering the dephlegmator through the spray pipe *AA*.

The reflux condensate oil from the dephlegmator *H*, mixed with fresh charging stock, passes through the reflux leg *BB*, and, by means of the hot oil pump *DD*, is discharged through pipe connection *EE* into the coil of heating tubes in the furnace, in which it is subjected to cracking conditions.

The dephlegmator *H* is of the perforated pan type, which gives efficient contact of oil and vapour. The use of charging stock and pressure distillate oil as means of cooling secures a refluxing action in the dephlegmator so that the light hydrocarbon vapours leaving the top of the dephlegmator through line *FF* may be of any quality desired. This light hydrocarbon vapour is condensed to a liquid as pressure distillate or crude gasoline in the cooling coil *GG*, from

which it passes into receiver *HH*, maintained under the operating pressure of the system. The pressure distillate discharges through the meter *SS* into a gas separating chamber *JJ*, from which it flows to a storage tank through the trap *LL*. The operating pressure on the system is controlled by the gas valve *RR* through which gas in excess of that necessary to maintain the pressure desired, leaves the receiver *HH*, mixing with that evolved from the pressure distillate due to the reduction of pressure in the separating tank *JJ*. The gas mixture flows through the line *KK* and connected pipes to the gasoline absorbtion system or to the burners in furnace *F*; it may be passed to storage to be converted into chemicals or shipped to gas companies to be blended with gas of low B.Th.U. value, such as water gas. If desired, the gas from the receiver *HH* may be taken off separately from the gas evolved from the pressure distillate in receiver *JJ*.

The residual oil method of operation of the cracking process may be carried out continuously for a period of 30 days or more, producing high yields of gasoline, a fuel oil residue passing all market specifications, and an insignificant amount of coke, ranging from a trace to a few pounds per barrel of charging stock.

The following data (p. 771) cover the commercial results obtained from the cracking of gas oil, wax tailings, topped crude and fuel oils from Kansas, the Mid-Continent field, Kentucky and California in the United States, and from Roumania. The amounts of charging stock given in the table were cracked in each case in a single continuous operation without shut-down of the apparatus.

(*c*) Simultaneous Cracking and Coking of Heavy Oils

In another method of operation the cracking process produces only pressure distillate oil (or crude gasoline), coke and gas. This mode of operation treats kerosene distillate, gas oil, topped crude, crude itself, or any other oil available and eliminates the use of coking stills which are necessary to prepare charging stock for cracking units limited to special distillate oil. Since, as is well known, the coking of heavy oils in shell stills is a costly operation, the simultaneous coking and cracking of heavy oil is important as a means of effecting great savings. Performing the cracking and coking in a single step requires no installation beyond that used in residual oil operation, the only changes being slight variations in the operating conditions.

RESULTS OF RESIDUAL OIL CRACKING OF TYPICAL OILS.

	California Gas Oil.	California Fuel Oil.	Kansas Gas Oil.	Kansas Fuel Oil.	Kentucky Topped Crude.	Mid-Continent Fuel Oil.	Roumanian 50-50 Mixture Fuel Oil and Wax Tailings.	Wax Roumanian Tailings.
Charging Stock—								
Specific gravity	0·899	0·956	0·862	0·901	0·904	0·910	0·910	0·883
Operating pressure, lb. ...	275	125	225	200	190	200	190	190
Total barrels cracked	49,350	14,809	19,749	15,141	9,874	10,906	21,220	37,640
Number of days operating ...	19·5	16·4	35	22·5	9·2	—	13·8	30·0
				Products derived from Cracking.				
Pressure Distillate Oil—								
Yield, per cent.	55·3	43·9	67·0	59·2	65·9	55·3	48·1	57·3
Specific gravity	0·765	0·785	0·756	0·753	0·749	0·755	0·767	0·767
Residuum Oil—								
Yield, per cent.	42·6	55·8	28·5	31·1	28·3	34·0	45·3	33·3
Specific gravity	0·983	1·01	1·01	0·990	1·048	0·986	0·975	0·979
Coke, pounds per barrel of oil charged	0·09	0·04	0·05	4·9	9·0	2·9	3·1	1·0
				Gasoline.				
Yields in per cent., based on charging stock passing through the cracking process once only	49·8	32·0	55·6	53·6	55·0	51·0	33·8 200°C. (392°F.) End Point.	40·1
				Furnace or Diesel Oil.				
	4·5	10·0	10·0	5·0	9·0	2·5	11·5	15·0

In the table following, data are presented from the simultaneous cracking and coking of different oils in commercial practice:—

RESULTS OF CRACKING AND COKING IN ONE OPERATION

	Pennsylvania Kerosene Distillate	Oklahoma Gas Oil.	Amarillo Texas Topped Crude.	Oklahoma Fuel Oil.	Mid-Continent Fuel Oil.
Charging Stock—					
Specific gravity .	0·8309	0·8514	0·8849	0·8911	0·9117
Total barrels cracked ...	6,246	3,407	5,507	5,470	14,188
Operating pressure, lb. ...	220	190	190	200	200
PRODUCTS DERIVED FROM CRACKING					
Pressure distillate Oil—					
Yield, per cent. of charging stock	86·5	91·8	84·4	79·6	76·6
Specific gravity	0·7447	0·7703	0·7624	0·7669	0·7711
Coke, lb. per barrel of oil charged ...	24·8	32·0	50·0	59·1	61·3
GASOLINE (Yields, in per cent., based on the charging stock passing once only through the cracking process.)	72·0	64·2	62·2	62·9	62·3
FURNACE OR DIESEL OIL (Yields, in per cent.)	6·8	24·5	18·8	11·1	13·0

(*d*) Anti-knock Properties of Cracked Gasoline

One of the most important problems of the oil industry to-day is the production of anti-knock motor fuels. Gasolines produced from crude oils of the major fields of the United States by simple distillation develop the familiar knocking sound when used in high compression automotive engines or in ordinary engines when labouring on hills with wide open throttle.

The knocking propensity of gasoline is primarily a function of its chemical composition. The work of Ricardo, Midgeley, Boyd and others, has shown that in their anti-knock properties the hydrocarbons of the various series stand in the following order:—

1. The paraffin hydrocarbons are the worst knockers.
2. The unsaturated hydrocarbons knock materially less than the paraffins.

3. The naphthene hydrocarbons are distinctly better as anti-knock material than either the unsaturated or the paraffin hydrocarbons.
4. The aromatic hydrocarbons are non-detonating under any practicable motor compression ratio.

For many years it was held that straight-run gasolines from paraffin base or semi-asphaltic base oils were the superior motor fuels. Of late, however, cracked gasolines have been in demand, and at present they are often sold at premium prices. In anti-knock properties they are better than the straight-run product. This is due to their higher content of olefine, naphthene and aromatic hydrocarbons. The superiority of cracked over straight-run gasoline from the same crude oil is brought out by the analyses in the tables following:—

(*e*) The Chemical Treatment of Cracked Gasoline

In the refining of cracked motor fuel by the usual methods, there is a distinct loss of hydrocarbons valuable for their anti-knock properties. There are no difficulties in treating cracked gasoline to meet any desired market specifications, but to refine some cracked motor fuels to water-white colour, odour, negative doctor and corrosion tests, and low sulphur content causes high economic loss. In particular, to demand a water-white motor fuel is an error, for as far as an automobile cylinder is concerned the combustion of gasoline bears no relation to its colour. As a matter of fact more and more motor fuel is being coloured, not only red, but also pink, purple, blue and green. Undoubtedly other colours will be used to complete the rainbow.

Odour is another test which is adhered to in a somewhat rigid manner, but which really should have small place in a specification for motor fuel. This is not serious, however, as a little water, caustic soda, sodium plumbite or adsorbent earth will eliminate the odour from motor fuel derived from high sulphur crudes such as predominate in California, Mexico and West Texas production without the use of sulphuric acid, while most of the Mid-Continent and eastern crude oils produce motor fuel of good odour without special treatment.

All cracked gasolines can be commercially treated with sulphuric acid, caustic soda, sodium plumbite and water, followed by fire and steam distillation. Recently Halloran[1] has found that by carrying out the acid treatment of cracked distillates at low temperatures

[1] Halloran, Oil Gas Journal, December 8, 1927, p. 36.

COMPARISON OF HYDROCARBONS IN STRAIGHT-RUN AND CRACKED MOTOR FUELS[1]

Hydrocarbons in per cent.	Cushing, Okla.		Somerset, Ky.	
	Straight-run.	Cracked.	Straight-run.	Cracked.
Unsaturated	1·6	10·9	3·6	12·5
Aromatic	4·9	19·8	5·3	14·9
Naphthene	23·7	18·0	20·6	11·8
Paraffin	69·8	51·3	70·3	60·8
Highest useful compression ratio	5·1	5·6	5·2	5·5

CHEMICAL ANALYSES OF CRACKED MOTOR FUELS

Hydrocarbons in per cent.	Tonkawa, Braman and North Kansas Topped Crude Oil.	Kentucky Fuel Oil.	Smackover Heavy Crude Oil.	North Texas Fuel Oil.	Lost Soldier Wyoming Crude Oil.	Spindletop Texas Crude Oil.
Unsaturated	16·1	14·4	14·7	16·0	11·7	14·7
Aromatic	17·8	22·5	27·5	18·6	15·9	17·3
Naphthene	12·8	10·0	21·2	11·7	14·5	32·6
Paraffin	53·3	53·1	36·6	53·7	57·9	35·4
Highest useful compression ratio	5·6	5·7	5·9	5·6	5·5	—

[1] Egloff, Oil and Gas Journal, April 29, 1926.

the losses may be greatly reduced. Below -9°C. (15°F.), sulphuric acid shows preferential solubility for sulphur compounds, while the vigorous polymerising effect and other chemical actions manifested at higher temperatures are markedly reduced. As a function of the type of motor fuel to be refined, the amounts of chemicals used and the order of adding them may be varied as required to cause the gasoline to pass market standards. The treating of cracked gasoline to meet drastic specifications adds to its cost in a threefold manner in that chemicals are consumed, the gasoline is depreciated in quality by the loss of anti-knock constituents, and there is actual loss of gasoline through reaction and solution in the acid and polymerisation of some of the hydrocarbons into high boiling compounds. It is therefore recommended that cracked gasoline be given a minimum of treatment in order to save chemicals, to conserve gasoline, and to retain its valuable properties.

(*f*) Furnace or Diesel Oil

One of the products of the cracking process is pressure distillate bottoms. This is an oil of narrow boiling range, which possesses special advantages for use in house heating. It is also an excellent oil for use in Diesel engines or it may be cracked to give additional yields of gasoline. It has a low cold test and viscosity, making it a satisfactory fluid combustible regardless of cold weather. A typical sample of this furnace or Diesel oil produced by cracking Mid-Continent stock had a cold test of -38°C. (-36°F.), and a viscosity (Universal Saybolt) of thirty-six seconds at 38°C. (100°F.).

The table shows the properties of representative examples of this oil.

(*g*) The Residual Oil Produced by Cracking

The residuum from the cracking process may range from a fuel oil of low viscosity to solid coke. From residual oils satisfactory lubricants can be made. Heavy pitchy oils may be oxidised to make asphalts. The preferred practice at the present time, however, is to conduct the cracking operation so that the residuum is a fuel oil meeting all market specifications. Such cracked residuum is, in fact, a premium fuel, as it has a considerably higher B.Th.U. content per barrel than the charging stocks.

At times the residual oil from cracking becomes the main product. This is the case when cracking is employed to change the properties of high cold test oils.

The viscosity and cold test of heavy crudes and fuel oils are of

PROPERTIES OF FURNACE OR DIESEL OIL FROM CRACKING OF TYPICAL OILS

Charging Stock.	Pennsylvania Kerosene Distillate.	California Fuel Oil.	Amarillo Texas Topped Crude Oil.	Spindletop Texas Crude Oil.	Kentucky Topped Crude.	Mid-Continent Topped Crude Oil.	Venezuela Fuel Oil.	Panuco Mexico Crude Oil
Specific gravity ...	0·8443	0·9001	0·8458	0·9082	0·9106	0·8838	0·8718	0·8822
Distillation analysis	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.
Initial B.P. ...	224	229	238	229·4	229	224	230	227
Per cent. distilled over 10	238	242	246	236	246	238	238	243
20	248	246	251	242	251	239	243	249
30	254	251	254	246	256	243	249	253
40	260	257	257	250	259	252	251	257
50	267	263	263	254	263	260	254	263
60	277	268	268	257	269	271	257	268
70	289	279	277	266	282	277	267	277
80	308	294	289	277	300	299	278	293
90	334	316	313	293	335	313	301	360
End B.P.	388	373	361	340	400	345	338	—

great importance. Much difficulty is experienced in the transport of heavy oils, which are produced in quantity in the United States, in California and Texas, and in Russia, Mexico, and other countries, on account of their high viscosity and high congealing temperature. Fuel oils from the distillation of some lighter stocks are also difficult to transport for the same reason. Often heavy oils, before introduction into pipe lines or tank cars, must be heated or cut back with distillate oil to increase their fluidity.

It has been found that when such heavy oils, either as crude or residuum therefrom, are subjected to heat and pressure and thus in part cracked to gasoline, the residual oil produced has a lower congealing temperature and lower viscosity than the original oil, and hence requires no heating either for transportation or use as fuel. In this type of operation the production of gasoline is incidental, the primary purpose of the cracking being the production of a fuel oil of desired properties.

COMPARISON OF CHARGING STOCKS AND RESIDUAL OILS FROM CRACKING[1]

	S.G.	Cold Test. °C.	Viscosity Saybolt Universal sec. at 38°C. (100°F.)	B.Th.U. per lb.
Louisiana Topped Crude—				
Original Oil	0·8827	17	144·2	19,570
Cracked Residuum ...	0·9211	−28	110	19,290
Louisiana Fuel Oil—				
Original Oil	0·8917	6	257	19,566
Cracked Residuum ...	0·918	−25	141·5	18,750
Louisiana Fuel Oil—				
Original Oil	0·972	2	10,257	18,314
Cracked Residuum ...	1·028	−29	122·9	18,144
Texas Fuel Oil—				
Original Oil	0·9147	17	347·5	19,143
Cracked Residuum ...	0·9267	−20	144	19,181
Mid-continent Fuel Oil—				
Original Oil	0·8927	13	181	19,857
Cracked Residuum ...	0·9303	−19	205	19,251

[1] Morrell & Egloff, Refiner and Natural Gasoline Manufacturer, April, 1923.

(*h*) Coke Formation in the Cracking Process

The greatest stumbling block in the development of the art of cracking oil has been the problem of coke formation. Millions of dollars have been expended to overcome the deposition of coke on

the heating portions of the cracking stills. A number of cracking installations in operation crack only low coke-forming oils and are strictly limited to selected charging stocks. The most modern cracking process treats all types of oils, whether they produce, as some oils do, less than 0·1 per cent. of coke, or produce coke equal to 25 per cent. of the weight of the oil. The yields of gasoline vary from 15 to over 75 per cent., with practically no coke deposition on the heating elements. The lower gasoline yield mentioned is obtained when operating primarily to reduce the viscosity of heavy oils. The facility with which high coke forming oils are cracked is seen from the fact that in operations where 320,000 lb. of coke were deposited in the reaction chambers only about 30 lb. were deposited in the heating tubes.

The percentage yields of gasoline and the amounts of coke per barrel of oil resulting from cracking a variety of charging stocks,[1] under varying conditions of temperature and pressure, are shown in the following table:—

CRUDE OIL

Charging Stock.	S.G.	U.S. Motor Gasoline per cent.	Coke lb. per bbl. Charging Stock
Healdton, Oklahoma	0·8783	45·0	5·0
Tarakan, Borneo	0·9452	32·0	23·0
Panuco, Mexico	0·9820	28·0	29·0
	0·9820	24·0	15·0

TOPPED CRUDE OILS

Lewistown, Montana	0·8348	48·0	5·0
Louisiana	0·8816	41·0	16·0
Amarillo, Texas	0·8849	62·2	50·0
Tonkawa, Oklahoma	0·8871	66·5	63·6
,, ,, ...	0·8871	65·8	60·6
,, ,, ...	0·8871	63·5	57·4
Smackover (Southfield), Arkansas	0·8899	49·0	19·9
,, ,, ,,	0·8922	56·4	18·6
,, ,, ,,	0·9013	54·0	18·8
Smackover, Heavy	0·9465	52·0	42·0
,, ,, ...	0·9478	49·0	44·6
,, ,, ...	0·9471	51·3	48·2
,, ,, ...	0·9471	50·4	46·4
Ranger, Texas	0·8984	41·0	14·0
Tonkawa and Burbank, Oklahoma	0·9042	46·0	27·0
,, ,, ,,	0·9042	55·0	65·0
,, ,, ,,	0·9042	34·0	11·0
,, ,, ,,	0·9042	47·0	19·0
,, ,, ,,	0·9042	36·0	10·0
Robberson, Texas	0·9402	33·0	35·0

[1] Egloff, National Petroleum News, March 3, 1926.

FUEL OILS

Charging Stock.	S.G.	U.S. Motor Gasoline per cent.	Coke lb. per bbl. Charging Stock
Kentucky	0·8855	53·9	20·0
,, ...	0·8927	58·0	29·0
,, ...	0·8984	58·0	25·0
Mid-Continent	0·8888	45·0	12·7
,, ...	0·8984	50·0	16·0
,, ...	0·8956	78·9	67·3
,, ...	0·9100	51·0	2·9
Oklahoma	0·8911	62·9	59·1
Tonkawa and Burbank, Okla. (Fuel and Gas)	0·8927	48·5	17·0
Kevin, Sunburst Montana ...	0·8927	61·6	42·9
Louisiana	0·8984	36·0	12·0
Kansas	0·9007	53·6	4·9
North Texas	0 9042	40·0	34·0
Luling, Texas	0·9135	47·1	14·0
Indiana, Illinois, Kentucky ...	0·9159	33·0	13·0
Miri, Borneo	0·9402	26·0	16·0
,, ,, ...	0·9402	27·0	16·0
California, Long Beach	0·9465	37·0	25·0
,, ,, ...	0·9465	36·0	21·0
,, ,, ...	0·9465	38·0	22·0
,, ,, ...	0·9529	34·0	21·0
California	0·9484	45·0	30·6
,, ...	0·9484	55·0	77·0
,, ...	0·9567	32·0	0·04
Venezuela	0·9765	23·0	17·0
,, ...	0·9792	26·0	27·0
,, ...	0·9725	32·0	35·0
Panuco, Mexico	1·002	21·0	20·0
,, ,, ...	1·002	18·0	17·0
GAS OILS			
Pennsylvania	0·8309	72·0	24·8
,, ...	0·8328	43·2	2·0
Oklahoma	0·8514	64·2	32·0
Mid-Continent	0·8550	40·0	1·3
,, ...	0·8654	76·0	5·4
Robberson, Texas	0·8602	43·0	6·3
Kansas	0·8623	55·6	0·05
California	0·8805	50·7	0·2
,, ...	0·8996	50·2	0·3
,, ...	0·9013	57·0	30·0
Roumania (Wax tailings) ...	0·8833	40·1	1·0
Venezuela	0·8927	35·0	9·1
,, ...	0·9042	42·0	22·0
Mexican	0·8984	39·0	10·0
,, ...	0·9279	41·0	18·0

Cracking process coke, a smokeless fuel, is being produced at the rate of approximately 1,000,000 tons a year. It is of high thermal value and in properties varies with the charging stock. Usually it has a honey-comb structure, being penetrated both by fine capillaries and larger interstices. The sulphur content varies quite widely and

is a function of the sulphur content of the oil subjected to cracking. Coke derived from certain low sulphur oils has been commercially used for electrodes for electro-chemical processes. The bulk of the production, however, is used for fuel, either in lump form, briquettes or powdered. In pulverised form it would be an excellent marine fuel.

PROPERTIES OF COKE FROM CRACKING

Charging Stock.	Volatile Matter.	Fixed Carbon.	Total Ash.	Sulphur	B.Th.U. per lb.
Smackover Arkansas Fuel Oil					
No. 1 Run	12·28	87·15	0·46	4·18	15,883
No. 2 Run	17·02	79·20	0·45	3·70	15,454
Mid-Continental Fuel Oil ...	12·5	84·9	0·9	1·13	15,876
Pennsylvania Gas Oil ...	9·60	89·14	0·2	0·45	15,899
Amarillo Texas Topped Crude	14·00	81·12	1·57	0·45	15,573
Oklahoma Fuel Oil	9·0	88·0	0·75	1·5	15,800
Kentucky Fuel Oil—					
No. 1 Test	10·07	88·92	0·55	0·45	16,241
No. 2 ,, ...	9·60	85·72	0·59	0·52	15,601
No. 3 ,, ...	11·65	87·42	0·54	0·66	16,403
No. 4 ,, ...	12·43	86·50	0·56	0·46	15,438
No. 5 ,, ...	3·75	94·60	0·84	0·36	15,625

(*i*) Gas from Cracking

One of the important by-products of the cracking process is gas, which is produced in large volume. The gas is valuable, not only as the ideal smokeless fuel, but because its content of unsaturated hydrocarbons makes it suitable for chemical uses, such as the production of ethyl, *iso*propyl and other alcohols, and glycols. These chemicals are useful both as solvents and as a means for preventing freezing of motor car radiators. The cracked gas is also valuable as an enricher of water or producer gas, as its thermal value is high.

The approximate quantity of gas produced by the cracking process during the year 1927 was 200,000,000,000 cu. ft. The composition of this gas varies with the charging stock and the temperature and pressure conditions maintained during the cracking reaction. Typical analyses, emphasising the unsaturated hydrocarbon content of the cracked gases, are shown in the following table:—

COMPOSITION OF CRACKED GASES

(per cent.)

Hydrogen ...	1·9	5·6	3·0	1·7
Ethylene... ...	1·9	4·7	2·7	6·3
Propylene ...	0·8	6·1	7·6	12·0
Butylenes ...	7·4	2·0	6·5	7·1
Paraffins ...	88·0	81·6	80·2	72·9

The following table covers the cracking of a number of oils and shows the amount of gas produced from each oil and its composition. It will be noted that there are wide variations, both between gases from different charging stocks and between the gases from the same charging stock when cracked under different conditions.

SUMMARY OF CRACKING OPERATION ON REPRESENTATIVE CRACKING STOCKS

(Yields based on the charging oil[1])

Sample.	Charging stock.	S.G.	Cracked Distillate.	U.S. Motor Gasoline.	Furnace or Diesel Oil.	Residuum	Gas cu. ft. Per Bbl.	Operating Pressure of System.	Liquid Temperature.
			per cent.	per cent.	per cent.	per cent.		lb.	°C.
1	Midcontinent gas oil	0·8468	79·90	44·3	34·0	7·1	303	120	461
2	Midcontinent Kerosene distillate	0·8328	90·86	52·6	34·3	0·0	266	135	454
3	North Texas Kerosene distillate	0·8275	96·61	41·9	53·2	2·6	69	135	458
4	Midcontinent Fuel Oil ...	0·8933	51·25	36·8	12·0	45·6	170	120	454
5	Midcontinent Topped crude ...	0·8822	60·01	41·6	15·9	34·1	189	120	452
6	Ranger Topped crude	0·8939	59·75	41·5	14·0	39·7	166	120	—
7	Healdton crude	0·8783	65·19	45·1	18·1	26·8	119	120	451
8	Montana Topped crude ...	0·8328	83·95	48·2	8·4	14·5	52	135	438
9	Kentucky Fuel	0·9013	59·7	43·9	12·0	34·5	185	120	463
10	Mexican Distillate	0·8967	60·19	39·6	19·6	35·3	145	120	436
11	Mexican Gas oil	0·9279	54·95	41·7	9·7	38·5	236	120	466
12	Panuco residuum (Mexico) ...	1·002	21·86	18·9	1·9	73·1	124	120	444
13	,, ,, ...	1·002	26·32	21·1	3·9	66·5	139	120	439
14	,, ,, ...	1·002	22·09	18·2	2·8	66·0	141	120	428
15	,, ,, ...	1·002	23·5	18·5	4·0	70·6	110	115	451
16	Panuco crude (Mexico) ...	0·9820	30·8	23·7	6·0	62·9	110	110	439
17	,, ,, ...	0·9820	34·1	28·2	4·5	64·2	173	110	441
18	Venezuela fuel	0·9765	30·9	23·3	5·7	61·0	111	110	448
19	,, ...	0·9765	38·5	26·9	10·0	52·2	137	105	444
20	Tarakan crude (Borneo) ...	0·9452	60·62	32·4	25·6	28·8	314	130	458
21	,, ,, ...	0·9452	61·69	30·6	27·8	26·6	348	125	464

[1] Egloff and Morrell, Ind. Eng. Chem., 17,32 (1925).

	Sample.	S.G. (Air = 1).	B.Th.U. per cu. ft.	Carbon Dioxide & Hydrogen Sulphide.	Olefines.	Oxygen.	Carbon Monoxide.	Hydrogen.	Paraffin Hydrocarbons and Nitrogen.
1	Midcontinent gas oil	0·894	1,123a	0·5	12·8	0·2	0·1	3·9	82·5
2	Midcontinent Kerosene distillate	0·851	1,123a	0·5	14·0	0·3	0·2	5·4	79·6
3	North Texas Kerosene distillate	0·660	1,395	0·0	8·7	0·6	0·4	11·1	79·2
4	Midcontinent Fuel Oil ...	0·847	1,702b	1·0	9·0	0·5	0·5	4·4	84·6
5	Midcontinent Topped Crude ...	0·900	1,680b	0·7	8·3	1·1	0·2	3·8	86·9
6	Ranger Topped Crude ...	0·850	1,562	0·4	8·4	0·5	0·0	4·4	86·3
7	Healdton Crude...	0·802	1,427	1·6	5·1	0·4	0·3	5·2	87·4
8	Montana Topped Crude ...	0·722	1,600b	0·0	5·2	0·6	1·4	10·2	82·6
9	Kentucky Fuel	0·806	—	0·61	2·21	0·61	2·24	3·06	91·27
10	Mexican Distillate	0·807	1,368	6·4	5·8	1·9	0·2	6·1	79·6
11	Mexican Gas Oil	0·827	1,600b	0·1	9·9	1·4	0·3	4·3	84·0
12	Panuco residuum (Mexico) ...	0·898	1,265	13·1	4·1	1·0	0·9	5·0	75·9
13	,, ,, ...	0·873	1,238	10·5	4·6	1·3	0·5	6·6	76·5
14	,, ,, ...	0·908	1,326	7·2	3·7	0·4	0·5	3·4	84·8
15	,, ,, ...	0·960	1,284	13·9	8·3	1·1	0·6	3·4	72·7
16	Panuco Crude (Mexico) ...	0·928	1,302	11·82	6·32	1·02	0·63	5·58	74·63
17	,, ,, ...	0·917	1,326	12·15	7·47	0·92	0·61	4·56	74·29
18	Venezuela Fuel	0·956	1,264	7·34	9·10	1·92	2·04	6·60	73·00
19	,, ,, ...	0·884	1,300	9·32	3·74	0·93	3·01	3·11	79·89
20	Tarakan Crude (Borneo) ...	0·784	1,317	0·6	5·2	0·3	0·3	4·0	89·6
21	,, ,, ...	0·787	1,388	0·4	5·8	0·6	0·2	5·6	87·4

a Gas from cracked distillate receiver.
b. Gas from cracked distillate separator.

THE CRACKING OF COAL TARS

(*a*) World Resources of Coal and Coal Tar

Coal is the world's greatest known resource of combustible material and the potential source of enormous quantities of oil. The amount of oil which can be produced from the known coal areas reaches astronomical figures. Through the cracking process, oil from coal could furnish over 1,000 billion barrels of gasoline: This supply would fill the needs of the 29,500,000 motor cars now in use throughout the world for over 2,500 years. The motor fuel would be of high anti-knock value, permitting its use in high compression motors, and materially increasing the mileage obtainable per gallon over that possible from ordinary gasolene.

The world's reserves of bituminous coal, sub-bituminous coal, and lignite are estimated at 7,000,000,000,000 metric tons. The distribution of this vast accumulation is shown in the following table:—

WORLD RESOURCES OF BITUMINOUS AND SUB-BITUMINOUS COAL[1] AND LIGNITE IN MILLIONS OF METRIC TONS

	Bituminous Coal.	Sub-Bituminous Coal and Lignite.	Total Resources.	Per cent. of World's Supply.
North America				
United States ...	1,955,521	1,863,452	3,818,973	55·2
Other countries ...	284,162	948,454	1,232,616	17·9
South America ...	31,397		31,397	0·4
Asia	760,098	111,851	871,949	12·6
Europe	693,162	36,682	729,844	10·6
Africa	45,123	1,054	46,177	0·7
Oceania	133,481	36,270	169,751	2·6
Total	3,902,944	2,997,763	6,900,707	100·0

[1] U.S. Bureau of Mines, 1927.

Compared with the total available supply of coal, the world's annual consumption, approximately one and a half billion tons, appears small. The 1927 world's production of coal, by continents and countries, is presented in the next table.

PRODUCTION OF COAL IN 1927

(In metric tons)

North America:	
Canada: Coal	12,329,539
Lignite	3,465,830
United States: Anthracite	73,164,000
Bituminous and Lignite	471,556,000
Europe:	
Belgium	27,573,550
Czechoslovakia: Coal	14,582,000
Lignite	19,769,000
France: Coal	51,779,300
Lignite	1,067,400
Germany: Coal	153,597,600
Lignite	150,805,711

PRODUCTION OF COAL IN 1927—*contd.*

	(In metric tons)
Europe (*contd*:):	
Saar...	13,595,824
Hungary: Coal	784,154
Lignite	6,243,384
Netherlands: Coal...	9,225,000
Poland: Coal	37,980,000
Lignite	77,000
Russia: Coal	31,000,000
Lignite	
Spain: Coal	6,023,000
Lignite	412,000
United Kingdom: Great Britain	259,516,600
Asia:	
India, British	21,000,000
Africa:	
Rhodesia, Southern	908,744
Union of South Africa	12,500,000
Australia:	
New South Wales	10,700,000
Total	1,475,000,000*

From U.S. Bureau of Mines, 1928.

*Estimates from a number of countries not listed are included in the total.

The utilisation of coal in the future will probably be in large measure through low temperature carbonisation. This process has the advantage of producing a smokeless solid fuel, gas and relatively large amounts of tar. The tar can be commercially converted into motor fuel by the cracking process.

There is a crying need for the use of smokeless fuel, particularly in large cities. The economic loss due to the smoke nuisance in thickly populated areas is tremendous, there being not only a waste of fuel, but also harm from accumulation of sooty material on buildings and personal effects. In addition, the detriment to the physical health and nerve force of society, due to living in an atmosphere contaminated with smoke, is of no small significance. All these evils could be eliminated by burning the smokeless fuels, coke and gas.

The potential yield of coke from the world's bituminous coal, semi-bituminous coal and lignite amounts to 3,000,000,000,000 tons. In addition to this amount the cracking of the tars produced in the low temperature carbonisation operation would yield, besides gasoline, 350,000,000,000 tons of cracked coke.

Fuel gas would also become available in enormous quantities, both from the carbonisation and from the cracking process. The potential production of this ideal fuel is estimated as 2,300,000,000,000,000 cu. ft.

The motor fuel available, were all the 4,000,000,000,000 barrels of tar derivable from the low temperature treatment of the world's

coal supply subjected to the cracking process, would amount to over 1,000,000,000,000 barrels, sufficient as has been said, to supply the needs of the world's present motors for over 2,500 years.

(*b*) Cracking of West Virginia Low Temperature Coal Tar

Quite extensive studies have been made of the cracking of low temperature tars. A West Virginia bituminous coal retorted at low temperature produced 25 gallons of tar per ton, the tar having the following characteristics:—

WEST VIRGINIA LOW TEMPERATURE COAL TAR

Specific gravity	1·074
Flash point, °C. (Cleveland Open Cup)	107
Fire point, °C. ,, ,,	127
Viscosity (Saybolt Furol) sec. at 25°C.	206
Water, per cent.	0·3

DISTILLATION ANALYSIS (A.S.T.M.).

Per cent. distilled over	°C.
10	196
20	246
30	267
40	290
50	307
60	343
70	356
80	368
90	393
End B.P.	393
Coke, per cent. by weight	11·3

This tar, cracked under 100 lb. pressure at an average temperature of 452°C. (845°F.), gave a yield of 30 per cent. of motor fuel containing 25 per cent. tar acids, or on an acid free basis, a 23 per cent. yield.

(*c*) Cracking of Ohio-Indiana Low Temperature Coal Tar[1]

An Ohio-Indiana bituminous coal tar cracked at 100 lb. pressure and an average temperature of 427°C. (800°F.), gave 34 per cent. of motor fuel, or 22 per cent. on a tar acid free basis. The characteristics of the fuel and a summary of the cracking operation are shown in the table following:—

CRACKING OF OHIO-INDIANA COAL TAR
PROPERTIES OF THE INITIAL TAR

Specific gravity	1·0794
Flash point, °C. (Cleveland Open Cup)	54
Fire point, °C. ,, ,,	82
Viscosity (Saybolt Furol) sec. at 50°C.	70
Tar acids, per cent.	27·5
Tar bases, per cent.	1·55

[1] Egloff and Morrell, International Bituminous Coal Convention, Nov. 15, 1926.

DISTILLATION ANALYSIS (A.S.T.M.).

Per cent. distilled over	°C.
10	208
20	232
30	257
40	291
50	348
60	372
78	366
Coke, per cent. by weight	22·0

SUMMARY OF THE RESULTS OF CRACKING

Pressure Distillate—	
Yield per cent. of charging stock	40·8
Specific gravity	0·9230
Motor Fuel	
Yield, per cent.	33·9
Yield, on tar acid free basis, per cent.	22·0
Coke, lb. per bbl.	193
Gas, cu. ft. ,,	525

(*d*) CRACKING OF UTAH LOW TEMPERATURE COAL TAR

Low temperature tar, produced by retorting eastern Utah coal in a modified Scottish oil shale retort, was cracked at 100 lb. pressure and approximately 435°C. (815°F.), and gave a yield of 24 per cent. of gasoline free from tar acids and bases. The product was high in anti-knock properties, having a benzol value of 65 per cent. A full statement of the cracking operation is presented in the following table:—

CRACKING OF UTAH COAL TAR

PROPERTIES OF THE INITIAL TAR

Specific gravity	0·9831
Flash point, °C. (Cleveland Open Cup)	82
Fire point, °C. ,, ,,	104
Viscosity (Saybolt Furol) sec. at 50°C.	32
Tar acids, per cent.	29·0
Neutral oil, per cent.	61·0

DISTILLATION ANALYSIS (A.S.T.M.).	°C.
Initial B.P.	183
Per cent. distilled over	
10	249
20	281
30	314
40	349
50	366
60	378
70	385
80	390
90	394
End B.P.	394
Coke, per cent. by weight	11·0

CRACKING CONDITIONS

Pressure lb. per sq. in.	110
Liquid temperature, °C.	435

PRODUCTS AND YIELDS, BASED ON THE CHARGING STOCK

Pressure Distillate Oil.	
Yield, per cent.	48·4
Specific gravity	0·8388
Coke, lb. per bbl.	120
Gas, cu. ft. per bbl.	618

PROPERTIES OF THE CRACKED GASOLINE
(Free from tar acids and bases).

Yield, per cent.	24·1
Specific gravity	0·7874
Initial B.P. °C.	43
End B.P., °C.	224
Sulphur, per cent.	0·15
Benzol equivalent, per cent.	65·0

PROPERTIES OF THE FURNACE OR DIESEL OIL

Yield, per cent.	17·9
Specific gravity	0·9315
Initial B.P., °C.	216
End B.P., °C.	399

(*e*) Cracking of Neutral Oil Distillate[1]

In some low temperature operations, economic conditions make it desirable to recover tar acids and pitch from the primary tar. There is left a neutral oil distillate. Such neutral oils form excellent cracking stocks. Neutral oil from West Virginia bituminous coal, cracked under a pressure of 250 lb. and temperature of about 454°C. (850°F.), yielded over 50 per cent. of motor fuel. The benzol equivalent of the product was more than 50 per cent. It constituted an excellent anti-knock fuel for high compression motors. The cracking operation produced approximately 84 lb. of coke per barrel of oil treated. The coke was practically ashless and had a calorific value of 16,000 B.Th.U. per lb. Gas was formed to the amount of 840 cu. ft. per barrel of oil cracked and approximated 1,300 B.Th.U. to the cu. ft.

The analysis of the initial oil is shown in the table below:—

PROPERTIES OF NEUTRAL OIL

Specific gravity	0·9478
Distillation Analysis (A.S.T.M.).	°C.
Initial B.P.	199
Per cent. distilled over	
10	232
20	249
30	263
40	277
50	291
60	302
70	321
80	338
90	368
98·5	374
End B.P.	374

[1] Egloff and Morrell, International Bituminous Coal Convention, Nov. 15, 1926.

Remarks
Trace of water.
3 per cent. at 210°C.
56 per cent. at 300°C.
Trace of coke.

Cracking of German Lignite Oils

Cracking tests were also made on a German lignite tar and a distillate oil from the tar. The tar was cracked at 90 lb. pressure and about 438°C. (820°F.). The yield of gasoline, on a tar acid and base free basis, was 38 per cent. of the oil treated. The distillate oil gave a 47 per cent. yield of gasoline at 150 lb. pressure and a temperature of approximately 454°C. (850°F.). The details of these runs are in the data below:—

CRACKING OF GERMAN LIGNITE TAR AND TAR DISTILLATE

PROPERTIES OF THE INITIAL OILS

	Tar.	Tar Distillate.
Specific gravity	0·9734	0·9265
Flash point °C. (Cleveland Open Cup)	—	127
Fire point °C. ,, ,,	—	149
Viscosity (Saybolt Furol) sec. at 25°C.	—	12·5
Sulphur, per cent.	1·8	—
Tar acid, per cent.	19·7	2·5
Tar bases, per cent.	1·0	—
Neutral oil, per cent.	79·3	—

Distillation Analysis (A.S.T.M.).

Per cent. distilled over	°C.	°C.
Initial B.P.	241	235
10	301	280
20	324	296
30	346	308
40	367	316
50	377·8	328
60	378·3	338
70	379·4	353
80	378·9	357
90	357	392

Coke, per cent. by weight 7·5

CRACKING CONDITIONS

Pressure (lb. per sq. in.)	90	150
Liquid temperature, °C.	438	454

PRODUCTS DERIVED FROM CRACKING

Pressure distillate oil, per cent.	64·4	67·1
Residuum	—	—
Coke, lb. per bbl.	77	50
Gas, cu. ft. per bbl.	767	571

PROPERTIES OF PRESSURE DISTILLATE OIL

	Tar.	Tar Distillate.
Specific gravity	0·7994	0·8132
Sulphur, per cent.	0·96	—
Tar acids, per cent.	6·5	—
Tar bases, per cent.	2·1	—

DISTILLATION ANALYSIS (A.S.T.M.).

	°C.	°C.
Initial B.P.	24	—
Per cent. distilled over		
10	71	70·6
20	110	111
30	138	130
40	160	154
50	183	178
60	207	198

PROPERTIES OF THE CRACKED GASOLINE
(Free from tar acids and bases).

Yield, per cent.	38·3	47·4
Specific gravity	0·7694	0·7762
Initial B.P., °C.	44	44
End B.P., °C.	224	227
Sulphur, per cent.	0·43	0·5

PROPERTIES OF GAS OIL

Yield, per cent.	19·3	17·6
Specific gravity	0·8996	0·9554
Initial B.P., °C.	221	238
End B.P., °C.	366	374

TREATMENT OF PRESSURE DISTILLATE DERIVED FROM CRACKING LIGNITE TAR

The pressure distillate oil may be treated by chemical reagents in the following manner, in order to produce a water white, light-stable motor fuel:—

1. Thoroughly agitate the oil with 5 per cent. by volume of 30° Bé. sodium hydroxide solution in order to remove the tar acids. Then settle the sludge and draw it off.
2. Wash well with water.
3. Agitate thoroughly with 5 per cent. by volume of a 10 per cent. sulphuric acid solution so as to remove the tar bases. Allow the acid sludge to settle. At this stage of the chemical treatment do not water wash.
4. Treat with 5 lb. of 66° Bé. sulphuric acid per barrel, drawing off the acid sludge after settling. There should also be no water wash at this stage of the procedure.
5. Agitate with an additional 5 lb. of 66° Bé. sulphuric acid. The acid sludge is allowed to settle and is then drawn off.
6. Thoroughly wash the oil with water, preferably by the shower method.
7. Neutralise the acid compounds left in the oil by the addition of 3 per cent. by volume of a 16° Bé. sodium hydroxide solution. The sludge is allowed to settle and is drawn off.

8. Subject the chemically treated pressure distillate oil to steam and fire distillation, at a relatively low temperature, approximately 135°C.
9. Wash with 8° Bé. sodium hydroxide solution to give a finished motor fuel.

Application of the above treatment to a sample of distillate produced a motor fuel of plus twenty-five colour Saybolt, stable to sunlight for 3 days. It was negative to the doctor and corrosion tests and contained 10 mg. of gum per 100 c.c. There was no trace of tar acids or bases present in the finished gasoline. The sulphur content of the motor fuel was 0·43 per cent.

THE CRACKING OF SHALE OILS

Oil shale deposits are located in many parts of the world, the principal deposits on the American Continent being those of the United States, Canada, Brazil, Argentina and Chile. In Europe they are found in the British Isles, France, Jugo-Slavia, Spain, Sweden, Bulgaria, Germany, Italy, Switzerland, Esthonia and Russia. There are also considerable amounts of oil shales in Australia, China, Japan, Arabia and Syria.

The total quantity of oil shale in the world is unknown. That it is huge is generally acknowledged. The world's potential shale oil production is estimated to be at least 300,000,000,000 barrels. By the use of the cracking process this oil would yield sufficient gasoline to operate all the motor cars in the world at the present time, for over 400 years. The cracking of shale oil into gasoline will be the dominating feature making profitable the utilisation of oil shale.

The by-products from cracking shale oil are gas and coke. The world's potential volume of shale oil would yield 180,000,000,000,000 cu. ft. of fuel gas and 11,250,000,000 tons of coke.

(*a*) The United States

The oil shale resources of the United States were estimated by the American Petroleum Institute to be 394,343,819,000 tons, which would yield 108,424,801,000 barrels of oil. The richest deposits occur in the Green River formation of the Rocky Mountain region, large beds being found in Colorado, Utah and Wyoming, while there are also deposits of importance in Montana, California, Indiana, Kentucky, Nevada and other States. The estimated amounts of oil shale and potential shale oil in the States having the largest deposits are as follows:—

	Oil Shale (in thousands of short tons).	*Shale Oil*[1] (in thousands of barrels (42 gal.)
Colorado	113,792,000	40,640,000
Utah	92,159,000	16,588,620
Kentucky	90,604,800	28,993,536
Indiana	69,696,000	13,939,200
California	13,939,200	5,575,680
Wyoming	7,176,000	1,291,680
Montana	6,969,600	1,393,920
Nevada	7,219	2,165
Totals	394,343,819	108,424,801

[1]Amer. Petroleum Institute Report on Petroleum Supply and Demand, 1925.

The 108,000,000,000 barrels of shale oil, by cracking, would give a total of over 54,000,000,000 barrels of gasoline, which would supply the 24,000,000 automobiles now in operation in the United States, for over 150 years.

Shale oils obtained by retorting Utah, Wyoming and California shales, have been distilled under pressure in such a way as to reproduce the results obtainable under commercial conditions.

Cracking of Wyoming Shale Oil

A topped shale oil from the Green River formation in Wyoming, with a boiling range of 252-391°C., was cracked under a pressure of 120 lb. In a residual oil type operation, a 35 per cent. yield of U.S. motor gasoline was obtained and in non-residual oil operation, 53 per cent. The gasoline was water white, doctor sweet, non-corrosive and of anti-detonating quality, equivalent to a 20 per cent. mixture of benzol with Pennsylvania straight-run gasoline. A detailed analysis of the cracking runs is presented in the data following:—

CRACKING OF GREEN RIVER, WYOMING, SHALE OIL
PROPERTIES OF THE INITIAL OIL

Specific gravity	0·9352
Flash point, °C. (Cleveland Open Cup)	127
Fire point, °C. ,, ,, ,,	138
Viscosity (Saybolt Furol), sec. at 50°C. (122°F.)	20
Sulphur, per cent.	1·1

Distillation Analysis (A.S.T.M.)	°C.
Initial B.P.	252
Per cent. distilled over	
10	277
20	306
30	337
40	349
50	373
60	377
70	381
80	387
90	391
Coke, per cent. by weight	5·4

CRACKING CONDITIONS

	Non-residual Oil Basis.	Residual Oil Basis.
Pressure (lb. per sq. in.)	120	120

PRODUCTS AND YIELDS BASED ON CHARGING STOCK

Pressure distillate yield, per cent. ...	64·5	50
Specific gravity	0·7852	0·7883
Residuum, per cent.	—	35·4
Specific gravity	—	0·9672
Coke (lb. per bbl.)	66	45
Gas (cu. ft. per bbl.)	650	400

PROPERTIES OF THE CRACKED GASOLINE

Yield, per cent.	52·9	35·2
Specific gravity	0·7741	0·7690
Initial B.P., °C.	48	52
End B.P., °C.	223	226
Sulphur, per cent.	0·71	0·70
Doctor sweet	Yes	Yes
Non-corrosive	Yes	Yes
Colour	W.W.	W.W.

PROPERTIES OF THE FURNACE OR DIESEL OIL

Specific gravity	0·9024	0·8973
Initial B.P.	232	232
End B.P.	377	391

Cracking of Utah Shale Oil

A somewhat heavier shale oil from Utah was cracked at a pressure of 120 lb. In a residual oil type operation at about 416°C., 44 per cent. of gasoline was obtained. Operating on a non-residuum basis at approximately 438°C., the yield of gasoline was 52 per cent. The gasoline upon refining was doctor sweet, non-corrosive and water white in colour. It had excellent anti-knock properties, which were markedly reduced during treatment. Chemical treatment of the non-residual type operation gasoline reduced its benzol value from 35 to 15 per cent. The gasoline from the residual oil type operation depreciated from 25 to 10 per cent. benzol equivalent.

Full details of the cracking are presented in the tabulation.

CRACKING OF UTAH SHALE OIL

PROPERTIES OF THE INITIAL OIL

Specific gravity	0·9402
Flash point (Cleveland Open Cup) °C.	82
Fire point ,, ,, ,, °C.	93
Viscosity (Saybolt Furol) sec. at 25°C.	70
B.S. (benzol), per cent.	0·7
Sulphur, per cent.	0·77
Nitrogen, per cent.	2·08

Distillation Analysis (A.S.T.M.)	°C.
Initial B.P.	160
Per cent. distilled over	
10	232
20	274
30	308
40	344
50	369
60	385
70	391
80	386
90	399
Coke, per cent. by weight	3·7

CRACKING CONDITIONS

	Non-residual Oil Basis.	Residual Oil Basis.
Pressure (lb. per sq. in.)	120	120
Liquid temperature, °C.	438	416

PRODUCTS AND YIELDS, BASED ON THE CHARGING STOCK

Pressure distillate oil yield, per cent.	69·9	50·2
Specific gravity	0·7936	0·7699
Residuum yield, per cent.	—	33·0
Specific gravity	—	0·9847
Coke (lb. per bbl.)	85	50
Gas (cu. ft. per bbl.)	624	390

PROPERTIES OF THE CRACKED GASOLINE

	Non-residual Oil Basis.	Residual Oil Basis.
Yield, per cent.	52·1	44·3
Specific gravity	0·7749	0·7715
Initial B.P., °C.	49	54
End B.P., °C.	224	224
Sulphur, per cent.	0·35	0·35
Doctor sweet	Yes	Yes
Non-corrosive	Yes	Yes
Benzol equivalent before treatment, per cent.	35	25
Benzol equivalent after treatment, per cent.	15	10
Colour	W.W.	W.W.

PROPERTIES OF FURNACE OR DIESEL OIL

Yield, per cent.	14·3	3·4
Specific gravity	0·9242	0·9365
Initial B.P., °C.	229	241
End B.P., °C.	354	346

Cracking of California Shale Oil

A shale oil of specific gravity 0·9868, from the Monterey area in California, was cracked, using 80 lb. pressure and a temperature of about 760°F. on a non-residual oil basis. 38 per cent. of gasoline and 23 per cent. of gas oil were obtained. The cracking operation is summarised in the following data:—

CRACKING OF MONTEREY, CALIFORNIA, SHALE OIL

PROPERTIES OF INITIAL OIL

Specific gravity	0·9868
Flash point, °C. (Cleveland Open Cup)	102
Fire point, °C. ,, ,, ,,	121
Viscosity (Saybolt Furol) sec. at 25°C.	84
Sulphur, per cent.	6·8
Nitrogen, per cent.	0·5

Distillation Analysis (A.S.T.M.)	°C
Initial B.P.	221
Per cent. distilled over	
10	275
20	302
30	341
40	358
50	373
60	381
70	386
80	399
90	371
End B.P.	405
Coke, per cent. by weight	7·5

CRACKING CONDITIONS

Pressure, lb. per sq. in.	80
Liquid temperature, °C.	404

PRODUCTS AND YIELDS, BASED ON THE CHARGING STOCK

Pressure distillate yield, per cent.	60·9
Specific gravity	0·8358
Residuum, per cent.	—
Coke, lb. per bbl.	115
Gas, cu. ft. per bbl.	680

PROPERTIES OF THE CRACKED GASOLINE

Yield, per cent.	40·0
Specific gravity	0·8251
Initial B.P., °C.	47
End B.P., °C.	225

PROPERTIES OF FURNACE OR DIESEL OIL

Yield, per cent.	20·2
Specific gravity	0·9350
Initial B.P., °C.	224
End B.P., °C.	399

(*b*) Scotland

The oil shale industry of Scotland is one of the oldest and the most highly developed in the world. The annual retorting of oil shale has been approximately 3,500,000 tons, from which 2,000,000 barrels of shale oil were produced. In view of the tax now levied on imports of gasoline, the cracking of shale oil should become a significant factor in the production of motor fuel.

Scotch shale oil has been cracked in both a non-residual oil and a residual oil type operation. Under an operating pressure of 120 lb., yields of gasoline of 59 and 50 per cent. respectively were obtained and in addition furnace or Diesel oil, coke and gas were produced. The gasoline was of good quality as regards colour, sweetness and sulphur content, and had low anti-knock properties, being equivalent to a 10 per cent. blend of benzol with Pennsylvania straight run gasoline. The detailed data of the cracking operation are shown in the table as follows:—

CRACKING OF SCOTTISH SHALE OIL

PROPERTIES OF THE INITIAL OIL

Specific gravity	0·8866
Sulphur, per cent.	0·55
Tar acids, per cent.	15·6
Tar bases, per cent.	14·4

Distillation Analysis (A.S.T.M.)	°C.
Initial B.P.	188
Per cent. distilled over	
10	222
20	253
30	287
40	354
50	385
60	384
70	371
80	360
90	353
End B.P.	386
Coke, per cent. by weight	6·1

CRACKING CONDITIONS

	Non-residual Oil Basis.	Residual Oil Basis.
Pressure, lb. per sq. in.	120	120
Liquid temperature, °C.	432	421

PRODUCTS AND YIELDS BASED ON THE CHARGING STOCK

Pressure distillate yield, per cent.		80·6	60·6
Specific gravity		0·7887	0·7732
Composition, in per cent.			
Tar acids	1·2		
Tar bases	3·9		
Unsaturated hydrocarbons absorbed by 80 per cent. sulphuric acid	16·9		
Absorbed by 95 per cent. sulphuric acid	25·1		
Sulphur, per cent.	0·40		
Residuum, per cent.		—	21·8
Specific gravity		—	0·9652
Coke, lb. per bbl.		42	33
Gas, cu. ft. per bbl.		470	325

PROPERTIES OF THE CRACKED GASOLINE

Yield, per cent.	59·2	49·6
Specific gravity	0·7715	0·7711
Initial B.P., °C.	44	49
End B.P., °C.	226	226
Sulphur, per cent.	0·19	0·19
Doctor sweet	Yes	Yes
Non-corrosive	Yes	Yes
Colour	W.W.	W.W.
Benzol equivalent, per cent.	10	10

PROPERTIES OF FURNACE OR DIESEL OIL

Yield, per cent.	18·2	7·9
Specific gravity	0·8838	0·8718
Initial B.P., °C.	227	
End B.P.	363	

Refining of the Pressure Distillate Oil

The treatment given the pressure distillate to produce a water white motor fuel consisted of the following steps:—

1. Agitation with about 3 per cent. by volume of 30° Bé. sodium hydroxide solution, adding same in two equal portions, and withdrawal of the sludge. This removed the tar acids and was accompanied by a solution loss of about 1·5 per cent.
2. Thorough washing with water.
3. Agitation with about 2 per cent. by volume of 80 per cent. sulphuric acid, followed by settling and removal of the sludge. The tar bases were here removed with a loss of about 4 per cent. The oil should not be washed with water at this point.
4. Agitation with 4 lb. per barrel of 66° Bé. sulphuric acid, settling and drawing off the sludge.
5. Agitation with a second 4 lb. portion of sulphuric acid, with removal of the sludge.
6. Thorough washing with water.
7. Neutralisation with about 1 per cent. by volume of 16° Bé. sodium plumbite solution, followed by settling and drawing off the sludge.
8. Thorough washing with water.
9. Distillation in a fire and steam still.

This treatment produced a water white, doctor sweet, non-corrosive and light stable motor fuel, with a sulphur content of 0·19 per cent. The treating losses amounted to approximately 12 per cent. of the volume of the pressure distillate.

Were a yellow fuel acceptable the above treatment could be materially shortened. Washing with caustic solution, as in step 1, followed by the application of dilute acid and by use of 2 to 3 lb. per barrel of 66° Bé. sulphuric acid produced a motor fuel with a colour of twenty-one Saybolt, rapidly turning yellow on exposure to sunlight.

(*c*) Australia

In Australia crude oil production is practically nil; hence the retorting and cracking of oil shale is of the greatest industrial importance.

The deposits of shale, particularly in New South Wales are extensive and rich, yielding on an average 2·5 barrels of oil per ton of shale. This oil can be cracked into over 50 per cent. of high anti-knock gasoline. As the known shale deposits of New South Wales alone could produce approximately 300,000,000 barrels of oil, this gives a potential production of 150,000,000 barrels of high anti-knock gasoline.

Tasmania has known oil shale deposits, covering 300 square miles, which contain at least a potential 320,000,000 barrels of shale oil. This could be converted, by cracking under pressure in commercial units, into 165,000,000 barrels of gasoline.

Several Australian shale oils have been cracked. In one run the crude shale oil as derived from retorting, was topped, yielding 16·5 per cent. gasoline stock, and the residual oil cracked at 125 lb. pressure and about 432°C. A yield of 55 per cent. gasoline on the topped oil was obtained, making a total gasoline yield of 62 per cent. of the crude shale oil. The cracking operation and results are described as follows:—

CRACKING OF AUSTRALIAN SHALE OIL

PROPERTIES OF THE INITIAL OIL (TOPPED SHALE OIL)

Specific gravity	0·8724

Distillation Analysis

	°C.
Initial B.P.	143
Per cent. distilled over	
10	194
20	227
30	254
40	278
50	302
60	322
70	346
80	371
90	398
95	421

CRACKING CONDITIONS

Pressure, lb. per sq. in.	125
Liquid temperature, °C.	432

PRODUCTS AND YIELDS BASED ON THE CHARGING STOCK

Pressure distillate yield, per cent.	66·5
Specific gravity	0·7809
Residuum yield, per cent.	27·8
Specific gravity	1·004
Coke, lb. per bbl.	4·0
Gas, cu. ft. per bbl.	168

PROPERTIES OF THE CRACKED GASOLINE

Yield, per cent.	55·3
Specific gravity	0·7749
Initial B.P., °C.	46
End B.P., °C.	224

PROPERTIES OF THE FURNACE OR DIESEL OIL

Yield, per cent.	10·1
Specific gravity	0·8686
Initial B.P., °C.	224
End B.P., °C.	341

(*d*) CANADA

That the oil shale deposits of Canada are enormous is well known, but there are no data available by which their extent may be estimated.

Retorting of a New Brunswick oil shale yielded approximately 47 gallons of oil per ton. The cracking of this oil, after removal of its lighter constituents by topping, produced a high grade motor fuel. The cracking was carried out under 150-175 lb. pressure, yielding 41 per cent. of gasoline in residuum operation, and 54 per cent. in non-residual oil type operation. The gasoline was sweet, low in sulphur, non-corrosive and water white, but rather low in anti-knock value. The data from the cracking operation is as follows:—

CRACKING OF NEW BRUNSWICK (CANADA) SHALE OIL

PROPERTIES OF INITIAL OIL

Specific gravity	0·9297
Flash point °C. (Cleveland Open Cup)	104
Fire point, °C. ,, ,,	121
Viscosity (Saybolt Furol) sec. at 25°C.	27

DISTILLATION ANALYSIS (A.S.T.M.).	°C.
Initial B.P.	218
Per cent. distilled over	
10	248
20	272
30	297
40	322
50	339
60	352
70	366
80	338
90	362
Coke, per cent. by weight	9·6

CRACKING CONDITIONS

	Non-residual Oil operation.	Residual Oil Operation.
Pressure, lb. per sq. in.	175	150
Liquid temperature, °C.	449	429

PRODUCTS AND YIELDS BASED ON CHARGING STOCK

Pressure distillate—		
Yield, per cent.	64·8	51·4
Specific gravity	0·7741	0·7694
Residuum—		
Yield, per cent.	—	25·9
Specific gravity	—	0·9951
Coke, lb. per bbl.	82	60
Gas, cu. ft. per bbl.	660	418

PROPERTIES OF CRACKED GASOLINE

Yield, per cent.	53·9	40·6
Specific gravity	0·7720	0·7624
Initial B.P., °C.	44	51
End B.P., °C.	223	223
Doctor Sweet	Yes	Yes
Non-corrosive	Yes	Yes
Sulphur, per cent.	0·16	0·16
Colour	W.W.	W.W.
Benzol equivalent, per cent.	5	5
Hydrocarbon Analysis, in per cent.		
Unsaturates	12·4	14·2
Aromatics	23·1	22·0
Naphthenes	7·7	5·3
Paraffins	56·8	58·5

PROPERTIES OF THE FURNACE OR DIESEL OIL

Yield, per cent.	6·8	7·0
Specific gravity	0·9236	0·9007
Initial B.P., °C.	232	229
End B.P., °C.	304	357

The Refining of the Pressure Distillate Oil

The amount of sulphur present in the charging stock and its distribution after cracking was as follows:—

	Per cent.
Topped shale oil	0·51
Pressure distillate	0·34
Gasoline (finished)	0·16

The chemical treatment of the pressure distillate in order to produce a water white, doctor sweet, non-corrosive and light stable gasoline is outlined below:—

1. Agitate the oil with 3 per cent. by volume of 30° Bé. sodium hydroxide solution. Then settle, drawing off the sludge.
2. Wash thoroughly with water.
3. In order to dry the oil, treat with 1 lb. of 66° Bé. sulphuric acid to the barrel. Allow it to settle and draw off the sludge acid.

4. Agitate thoroughly with 4 lb. of sulphuric acid, allow the sludge acid to settle and draw it off.
5. Follow with a further 5 lb. of sulphuric acid, agitating thoroughly, permitting the sludge acid to settle and then drawing off.
6. Wash thoroughly with water, drawing it off after settling.
7. Neutralise the acid compounds in the pressure distillate oil with about 1 per cent. by volume of 16° Bé. sodium plumbite solution with thorough agitation. The plumbite solution should be allowed to settle and then drawn off.
8. Distil the chemically treated oil with fire and steam to finished gasoline. Usually the maximum temperature of the still is 135°C.

(*e*) FRANCE

As the crude oil production of France in negligible in quantity, France has endeavoured by means of prizes to stimulate the commercial production of motor fuel from sources other than petroleum. Much work has been carried on in the exploitation of the oil shale resources, which have been worked since 1845. The oil shale industry has not, however, risen to its highest possibilities. As the government is taking a keen interest in this resource, the future should see advances in this industry with the use of the cracking process.

A sample of Autun shale oil was cracked at 120 lb. pressure and 426°C. yielding 51 per cent. of gasoline and about 8 per cent. of furnace or Diesel oil.[1] The results are given in detail in the following tabulation:—

CRACKING OF AUTUN (FRANCE) SHALE OIL

PROPERTIES OF INITIAL OIL

Specific gravity	0·8956
DISTILLATION ANALYSIS (A.S.T.M.).	°C.
Initial B.P.	121
Per cent. distilled over	
10	196
20	224
30	254
40	291
50	321
60	354
70	382
80	410
90	427
End B.P.	429

[1] Morrell and Egloff, Natl. Petroleum News, April 28, 1926.

CRACKING CONDITIONS

Pressure, lb. per sq. in.	120
Liquid temperature	426°C

PRODUCTS AND YIELDS BASED ON CHARGING STOCK

Pressure distillate	
Yield, per cent.	61·0
Specific gravity	0·7844
Residuum	
Yield	27·7
Specific gravity	1·030
Coke, lb. per bbl.	20
Gas, cu. ft. per bbl.	252

PROPERTIES OF THE CRACKED GASOLINE

Yield, per cent.	51·0
Specific gravity	0·7762
Initial B.P., °C.	48
End B.P., °C.	224

PROPERTIES OF THE FURNACE OR DIESEL OIL

Yield, per cent.	7·6
Specific gravity	0·8778
Initial B.P., °C.	216
End B.P., °C.	348

(*f*) ESTHONIA

In a monograph on oil shale by Cronshaw, published by the Imperial Institute of Great Britain, there appears the following:—

"Deposits of oil shale are known to extend in Esthonia from the west coast, near Port Baltic, to the north shore of Peipus Lake, an approximate distance of 100 miles. The fields have been estimated to contain a total of 40,000 million tons of oil shale. In the eastern section the aggregate thickness of shale is 8 ft. There are five seams in all, varying in thickness from 8 to 30 in. Three occur together, totalling 4 ft. The overburden, soil and chalk, is 6 ft. in thickness. A ton of raw shale with 13·7 per cent. moisture, yielded 35 cu. ft. of gas and water, which contains acetone, methyl alcohol, acetic acid and ammonia, and about 60 gal. of crude oil, containing 19 per cent. light, and 81 per cent. heavy oils. A test of Esthonian shale by Schamarin gave the following results by dry distillation."

	Per cent.
Oils and tar	29·07
Gases	21·33
Coke	7·64
Ash	40·15
Water	1·81

Large scale retorting tests were made in the United States on a shipment of Esthonian shale. Approximately 50 gallons of oil per ton of shale was obtained. A portion of this oil was subjected to the cracking process. It had the following properties:—

ESTHONIAN SHALE OIL

Specific gravity	0·9854
Flash point °C. (Cleveland Open Cup)	60
Fire point °C. ,, ,,	90

Distillation Analysis (A.S.T.M.).

	°C.
Initial B.P.	157
Per cent. distilled over	
10	224
20	262
30	300
40	341
50	360
60	368
70	370
80	371
90	349
Coke, per cent. by weight	11·8

In cracking, a non-residual oil run was made at 140 lb. pressure and a residual oil run at 135 lb. The gasoline yields were 42 and 36 per cent., respectively, the product being sweet, non-corrosive, water white, and possessing a benzol value of 27 per cent. A tabular description of the cracking operation is given:—

CRACKING OF ESTHONIAN SHALE OIL

CRACKING CONDITIONS

	Non-residual Oil Basis.	Residual Oil Basis.
Pressure, lb. per sq. in.	140	135
Liquid temperature, °C.	421	399

PRODUCTS AND YIELDS BASED ON CHARGING STOCK

Pressure distillate oil—		
Yield, per cent.	57·3	42·5
Specific gravity	0·8348	0·7852
Residuum—		
Yield, per cent.	None	18·3
Specific gravity	—	1·018
Coke, lb. per bbl.	105	88
Gas, cu. ft. per bbl.	974	596

PROPERTIES OF THE CRACKED GASOLINE

Yield, per cent	42·1	35·5
Specific gravity	0·7914	0·7818
Initial B.P., °C.	53	49
End B.P., °C.	223·5	223
Doctor Sweet	Yes	Yes
Non-corrosive	Yes	Yes
Colour	W.W.	W.W.
Benzol equivalent, per cent.	27	—
Hydrocarbon Analysis, in per cent.		
Unsaturated		21·0
Aromatic		28·7
Naphthene		10·9
Paraffin		39·4

PROPERTIES OF THE FURNACE OR DIESEL OIL

Yield, per cent.	10·0	4·2
Specific gravity	0·9951	0·9236
Initial B.P., °C.	232	239
End B.P., °C	414	377

CRACKING OF BITUMINOUS TARS AND ASPHALTS[1]

One of the largest deposits of hydrocarbon material in the world is the bituminous sands of Alberta, Canada. It is estimated that this deposit contains over 100,000,000,000 barrels of tarry hydrocarbons. This bitumen, on cracking, yields more than 35 per cent. of high anti-knock motor fuel. The gasoline potentially derivable from the tar sands is, therefore, over 35,000,000,000 barrels, enough motor fuel to supply the world demand at the present rate of consumption for over 100 years. At the same time, the cracking produce would produce approximately 7,000,000,000 tons of coke and 100,000,000,000,000 cu. ft. of gas.

There are a number of other asphaltic deposits in various parts of the world, which would prove valuable sources of cracked motor fuel. The deposits vary from semi-liquid asphalts to hard pitches, and often contain sand and other solids in admixture. Such bituminous substances occur in the United States, Trinidad, Cuba, Mexico, Argentina, Italy, France, Russia, Germany, Switzerland, Spain, Portugal, Austria, Syria, Mesopotamia, Japan and Africa. In only a few countries have even approximations of the bitumen content of these deposits been recorded. In the aggregate they are a vast supply of raw material for the production of gasoline, whenever economic demands justify their use.

The bitumen content of the Canadian tar sands ranges between 15 and 25 gallons per ton. The minimum estimate of the area of the deposit is 1,000 sq. miles. To quote from an official report:—

"There appears to be little change in the nature of the bitumen contained in the bituminous sand throughout the area. It is always a heavy, dark brown, viscous oil, and with few exceptions has a specific gravity between the values of 1·010 and 1·035 (25°C./25°C.). A few values as high as 1·050 were found, but these are in all probability to be accounted for by weathering."

A sample of bitumen from these tar sands, separated by treatment with dilute sodium silicate solution and hot water, was cracked in a non-residual oil type operation at 90 lb. pressure and a temperature of approximately 399°C. A 36 per cent. yield of gasoline was

[1] Egloff & Morrell, American Institute Chemical Engineers, Dec. 6, 1926.

obtained, of water white colour, doctor sweet and non-corrosive. Full details of the cracking are given in the table following:—

CRACKING OF BITUMEN FROM ALBERTA TAR SAND

PROPERTIES OF THE INITIAL TAR

Specific gravity	1·031
Sulphur, per cent	5·1
Water, per cent.	2·5

Distillation Analysis (A.S.T.M.).

Per cent. distilled over	°C.
10	282
20	263
30	310
40	320
50	338
60	326
70	307
77	348
Coke, per cent. by weight	25·0

CRACKING CONDITIONS

Pressure, lb. per sq. in.	90
Liquid temperature, °C.	399

PRODUCTS AND YIELDS

Pressure distillate, per cent.	56·0
Gasoline, per cent.	36·3
Furnace or Diesel Oil, per cent.	1·7
Coke, lb. per bbl. (15,000 B.Th.U. per lb.)	139
Gas, cu. ft. per bbl. (1,000 B.Th.U. per cu. ft.)	1,000

PROPERTIES OF THE PRESSURE DISTILLATE

Specific gravity	0·8309
Unsaturated hydrocarbons, per cent.	40

Distillation Analysis (A.S.T.M.)

Per cent. distilled over	°C.
10	70
20	107
30	133
40	153
50	181
55	194
60	209

PROPERTIES OF THE CRACKED GASOLINE

Specific gravity	0·7762
Hydrocarbon analysis.	Per cent.
Unsaturated hydrocarbons	27·2
Aromatic hydrocarbons	24·7
Naphthene hydrocarbons	12·3
Paraffin hydrocarbons	35·8

DISTILLATION ANALYSIS (A.S.T.M.)

	°C.
Initial B.P.	42
Per cent. distilled over	
10	76
20	97
30	114
40	130
50	143
60	156
70	169
80	184
90	202
End B.P.	225

PROPERTIES OF THE FURNACE OR DIESEL OIL

DISTILLATION ANALYSIS (A.S.T.M.).

	°C.
Initial B.P.	227
Per cent. distilled over	
10	241
20	249
30	258
40	267
50	278
40	291
70	310
80	338
90	391
End B.P.	404

THE CRACKING OF WOOD TARS[1]

Another potential source of motor fuels is the cracking of wood tars. The amount of wood tar which could be made available in the world is not known, but that it is large is certain.

Wood tars of two different types were subjected to cracking conditions, and gave yields of over 25 per cent. of gasoline. One of these was obtained from sawdust from Douglas fir, while the other was derived from pine wood, using so-called "light-wood," the general term for the stumps, knots, and limbs of resinous pine trees of the South Atlantic states. Statistics indicate that only 35 per cent. of the standing tree is converted into lumber and approximately 65 per cent. is waste in the form of limbs, stumps, tops, sawdust and shavings. It is, therefore, in the interest of conservation to find suitable methods of converting these waste materials into products of economic value. The making and cracking of wood tar would produce motor fuels, solvents, paint thinners and resins.

CRACKING OF DOUGLAS FIR TAR

From the carbonisation of Douglas fir, tar was obtained in the amount of approximately 40 gallons per ton of wood. On cracking

[1] American Chemical Society Meeting, Sept., 1926, Morrell & Egloff.

at 75 lb. pressure in non-residual oil type operation this tar produced 26 per cent. of gasoline. The characteristics of the wood tar, and the distillate derived from it, as well as a summary of the cracking operation, are shown below.

ANALYSIS OF THE WOOD TAR USED FOR CRACKING

	Per cent.
Oil	61·5
Aqueous distillate	15·5
Coke, pitch and gas	23·0

CHEMICAL ANALYSIS OF THE DISTILLATE OIL

	Per cent.
Fraction I. 100-150°C.	
Turpentine substitute	1·25
Fraction II. 150-250°C.	
Tar acids	5·4
Tar bases	0·0
Neutral oil	14·0
Fraction III. 250°-Coke	
Tar acids	8·5
Tar bases	0·5
Neutral oil	25·0
Coke and gas	0·35

CRACKING CONDITIONS

Pressure, lb. per sq. in.	75

PRODUCTS AND YIELDS BASED ON THE CHARGING STOCK

Pressure distillate—	
Yield per cent.	48·6
Specific gravity	0·7826
Residuum	—
Water, per cent.	19·3
Coke, lb. per bbl.	105
Gas, cu. ft. per bbl.	727
Motor fuel, yield per cent.	26·2
Furnace or Diesel oil—	
Yield, per cent.	21·4
Specific gravity	1·035

The cracked motor fuel contained tar acids to the extent of 18·5 per cent. The ultimate yield of motor fuel from the cracking of wood tars on a tar acid-free basis would be approximately 30 per cent.

In the event that solvents are desired, such as turpentine substitutes and pine oils, the cracked distillate may be fractionated into the following products:—

Product.	Boiling Range. °C.	Per cent.
Light solvent	to 154	6·1
Turpentine substitute	154–190	21·9
Pine oil equivalent	190–230	25·7
Pressure distillate bottoms		46·3
		100·0

COMPARATIVE ANALYSES OF DEHYDRATED WOOD TAR, CHARGING STOCK, NORMAL DISTILLATE, AND PRESSURE DISTILLATE FROM SAME (in per cent.).

	Tar.	Tar Distillate.	Pressure Distillate.
Tar acids	24·15	33·35	22·35
Tar bases	0·59	0·80	0·25
Unsaturated hydrocarbons ...	45·34	62·70	15·10
Aromatic ,, ...	—	—	60·00
Paraffin and naphthenes (by difference) ...		—	2·30
Aromatics, paraffins and naphthenes (by difference) ...	2·31	3·15	—
Coke, gas and pitch	27·61	—	—
Totals	100·00	100·00	100·00

The above analyses show that, whereas the distillate from the charging stock contains 62·7 per cent. of unsaturated hydrocarbons the cracked distillate contains only 15 per cent. of such hydrocarbons. The tar acids have in part been converted to hydrocarbons, and there has been a marked conversion of unsaturated into aromatic hydrocarbons. The pressure distillate contains 60 per cent. of aromatics, indicating that the motor fuel produced from such pressure distillate is of the highest anti-knock qualities, so effective an anti-detonant, in fact, that it may be used for blending with other motor fuels which are deficient in aromatic hydrocarbons.

THE CRACKING OF VEGETABLE OILS[1]

Among the most interesting sources from which motor fuel can be produced by cracking are the vegetable oils, such as palm oil, cottonseed oil, and coconut oil. When the possibilities of the tropics are more thoroughly exploited, these oils can be produced in very large quantities. They can all be converted by the cracking process into high yields for motor fuel and no doubt will be cracked when economic conditions warrant their use.

In experimental cracking runs palm oil and cottonseed oils have produced over 60 per cent.of motor fuel. As an illustration of this type of cracking the data from palm oil are given in the table following:—

CRACKING OF PALM OIL

PROPERTIES OF THE INITIAL OIL

Specific gravity	0·9129

[1] Full report is in course of preparation by Faragher, Morrell and Egloff.

Distillation Analysis.	°C.
Initial boiling point	308
Per cent distilled over	
10	322
20	321
30	324
40	329
50	330
60	331
70	323
80	325
90	324
End boiling point	294
Coke, per cent. by weight	1·7

CRACKING CONDITIONS

Pressure, lb. per sq. in.	135
Liquid temperature, °C.	438

PRODUCTS AND YIELDS BASED ON CHARGING STOCK

Pressure distillate—	
Yield per cent.	76·6
Specific gravity	0·7669
Water	3·5
Residuum	—
Coke, lb. per bbl.	28
Gas, cu. ft. per bbl.	709

PROPERTIES OF THE CRACKED GASOLINE

Yield, per cent.	62·0
Specific gravity	0·7539
Initial boiling point, °C.	46
End boiling point, °C.	225

THE CRACKING OF FISH OILS

A further source of motor fuel by the cracking process though from a world standpoint a minor one, is fish oil. Some countries, which produce fish oil in large quantities with no ready outlet for it, may find it profitable to convert it into gasoline. We have found that Menhaden fish oil can be cracked into over 45 per cent. of motor fuel. This cracking is an extension of the classic work of the late Prof. Carl Engler, who cracked fish oils in order that from his results on the heat and pressure decomposition of such oils he might elucidate the transformations occurring during the genesis of petroleum. The detailed results of the cracking of Menhaden oil follow:—

CRACKING OF MENDADEN FISH OIL

PROPERTIES OF THE INITIAL OIL

Specific gravity	0·9446

[1] Full report is in course of preparation by Faragher, Morrell and Egloff.

Distillation Analysis	°C.
Initial boiling point	307
Per cent. distilled over	
10	327
20	327
30	313
40	314
50	316
60	316
70	317
80	302
90	310

CRACKING CONDITIONS

Pressure, lb. per sq. in.	100
Liquid temperature, °C.	446

PRODUCTS AND YIELDS BASED ON THE CHARGING STOCK

Pressure distillate—	
Yield per cent.	67·9
Specific gravity	0·7831
Water	6·1
Coke, lb. per bbl.	57
Gas, cu. ft. per bbl.	790

PROPERTIES OF THE CRACKED GASOLINE

Yield, per cent.	47·5
Specific gravity	0·7653
Initial boiling point, °C.	46
End boiling point, °C.	224

THE CRACKING OF PEAT OILS

Peat has been used for fuel for many centuries, probably since the dawn of history. Its use was recorded by Latin authors during the conquests of northern and western Europe by the Romans. It has been burned for hundreds of years in Russia, Ireland, Finland, Denmark, Sweden, Holland and Germany, and was used in the pioneer days of the United States. In the past peat has been employed primarily as a solid fuel; however, by low temperature carbonisation a tar is produced which can be converted into motor fuel.

The areas of peat land in various parts of the world are enormous in their extent, and in the amount of peat which they contain, as is shown in the following tabulation[1]:—

[1] The Peat Resources of Ireland, P. F. Purcell, lecture before Royal Dublin Society, March 5, 1919.

PEAT DEPOSITS OF THE WORLD

Country.	Area in square miles.	Authority.	Estimated peat content, dry basis, tons.
Russia	65,000	Hausding	65,000,000,000
Finland	38,000	,,	38,000,000,000
Canada	37,000	E. Haanel	37,000,000,000
Sweden	19,000 (2,000 sq. miles of peat fuel bogs)	Wallgren	19,000,000,000
United States	11,200	C. A. Davis	14,000,000,000
Germany	9,900	Hausding	9,900,000,000
Great Britain	9,400	Thrope	9,400,000,000
Ireland	4,700	Bog Commissioners	3,700,000,000
Norway	2,900	Hausding	2,900,000,000
Austria	1,500	,,	1,500,000,000
Denmark	400	,,	400,000,000
		Total	200,800,000,000

The approximate distribution of known peat in the United States is given by Odell and Hood[1] as follows:—

State.	Areas, acres.	Quantity in tons.	
Northern Region.			
Minnesota	5,217,000	6,835,000,000	
Wisconsin	1,000,000	2,500,000,000	
Michigan		1,000,000,000	
Iowa		22,000,000	
Illinois	42,000	10,000,000	
Indiana		13,000,000	
Ohio	50,000	50,000,000	
Pennsylvania		1,000,000	
New York	800,000	480,000,000	
New Jersey		15,000,000	
Maine		100,000,000	
New Hampshire		1,000,000	
Vermont		8,000,000	
Massachusetts		12,000,000	
Connecticut		2,000,000	
Rhode Island		1,000,000	
			11,050,000,000
Atlantic Coastal region.			
Virginia and North Carolina.		700,000,000	
Florida		2,000,000,000	
Other States		2,000,000	
			2,702,000,000
Other regions.			
Gulf Coast (excluding Florida)		2,000,000	
California	60,000	72,000,000	
Oregon and Washington		1,000,000	
			75,000,000
Total			13,827,000,000

The figures for the peat resources of Ireland and the United States are generally accepted estimates. Those for the other countries are made on the basis of 1,000,000 tons per sq. mile, a figure about

[1] United States Bureau of Mines, Department of Commerce, Bulletin 253 (1926).

midway between Ireland's 785,000 tons and the 1,250,000 tons per sq. mile of the United States. The world supply of peat thus aggregates 200,000,000,000 tons.

The amount of volatile organic matter in dry peat is relatively high. By low temperature carbonisation it would average at least one-half barrel of tar per ton. The potential world supply of peat tar is therefore over 100,000,000,000 barrels. Hausding[1] quotes from Vohl a list of the products from 1,000 Kg. of peat, as follows:—

	Kilos.
Peat oil	7·9094
Solar oil	8·5463
Lubricating oil	
Paraffin	1·1893
Creosote and carbolic acid	19·8114
Sal-ammoniac	0·9196
Acetic acid	6·0040
Wood spirit	2·9028
Coke	300·0000
Butyric and Valeric acids	0·7862

Odell and Hood[2] obtained the following products by the carbonisation of a peat containing 20 per cent. moisture:—

One short ton of peat:
12,285 cu. ft. of gas (340 B.Th.U. per cu. ft.). 540 lb. of char.

22·85 U.S. gallons of tar:
- 0·39 U.S. gallon of refined spirits.
- 16·19 U.S. gallons of oil.
- 48·0 lb. of pitch.

93·75 U.S. gallons of liquor:
- 22·1 lb. of ammonium sulphate
- 1·28 lb. of methyl alcohol.
- 1·02 lb. of acetone.
- 6·7 lb. of acetic acid.

The results of the distillation analysis of the tar were as follows:—

Water content of the tar as collected, per cent. by weight	5·5
Settling point, °C.	40
Calorific value, B.Th.U. per lb., dry	16,210
Free carbon, per cent.	0·17
Ash, per cent.	0·15
Sulphur, per cent.	0·10
Tar distillation.	per cent. by weight.
0° to 170°C.	2·3
170° to 230°C.	13·6
230° to 270°C.	13·6
270° to 310°C.	24·5
310° to 334°C.	16·9
Pitch	25·6
Loss	3·5
Total	100·0
Paraffin wax in the tar, per cent. by weight	6·5
Melting point of the refined wax, °C.	53
Specific gravity of pitch	1·142

[1] A Handbook on the Winning and Utilisation of Peat. Dept. of Scientific and Industrial Research, London, 1921.

[2] Loc cit., p. 76.

No work has as yet been done on the cracking of peat oils. But based on experience from thousands of cracking tests with oil of a large number of types, it is certain that the cracking of peat oil would yield a minimum of 35 per cent. of motor fuel. The world's peat resources could furnish enough motor fuel to operate all the existing motor cars for over 100 years.

THE FUTURE OF CRACKING

The primary use of the cracking process up to the present time has been the conversion of hydrocarbon oils into motor fuels. But tremendous as this achievement is, it does not represent the full possibilities of cracking. The cracking process can convert any liquid carbonaceous material into practically any hydrocarbon product. The usual bulk products have already been mentioned—gasoline, kerosene, furnace or Diesel oil, residual oil, coke and gas. From these a host of other materials can be obtained, including alcohols, glycols, paint thinners, solvent oils, and lubricating oils, made from the cracked oils, and asphalt from the residuum by oxidation.

But the flexibility of the cracking process does not stop with even this list of products. The cracking operation can be so controlled as to give maximum yields of the hydrocarbons of any desired series, or even to give a large yield of a single hydrocarbon. The products of cracking include hydrocarbons of all the series—paraffins, naphthenes, olefines, diolefines, acetylenes and aromatics. By this production of hydrocarbons of the most varied sorts the cracking process opens the door to the only partially explored field of the chemical by-products of petroleum.

The paraffin hydrocarbons have as yet found use principally as fuel. They make up a large proportion of cracked products. The lower ones are readily obtainable in pure form and at the present time possess limited utility because they are undesirable in gasoline. Work is urgently needed to develop means for converting these substances into useful derivatives. Of the naphthene series, individual members may now be produced by cracking, and no doubt uses will be found to which they are exactly suited.

The olefines, being reactive substances, have many more uses than the paraffins or naphthenes. By proper regulation of the cracking process, any desired member of this series may be produced, such as ethylene, propylene, the butylenes, etc. Their utilisation is an immense and promising field. By chlorination these hydrocarbons

may be made into valuable solvents. They can also readily be converted into alcohols, certain of which, such as ethyl and *iso*propyl alcohols, and several glycols have already been produced on a commercial scale, while many others have been made in the laboratory. Those which are now curiosities will no doubt prove useful in the future. The olefines should also be convertible into fatty acids and soaps.

The diolefines, also present in cracked products, are other substances of great potential value. Of this series, butadiene has already been isolated. Being closely related to the rubber hydrocarbons, the diolefines may well serve as starting materials for the successful production of synthetic rubber. Likewise they can be polymerised into resins, which can be used as insulating material and may find employment in other of the multitudinous uses to which the familiar aldehyde-phenol type resins have been put. They should also be useful as lacquer and varnish bases.

Acetylene has been found in cracked gases. It is likely that higher members of this series are also produced in cracking. As a source of the higher acetylenes, which are extremely difficult to synthesise, the cracking process may prove of great value.

The possibilities opened up by the production of aromatic hydrocarbons from petroleum are also of large extent. In recent years, as a result of the efforts to produce better anti-knock gasoline, the proportion of aromatics in cracked motor fuel has been greatly increased. The utilisation of the aromatic hydrocarbons for synthetic purposes opens up to the oil industry a new world of possibilities—dyes, pharmaceuticals, resins, explosives, perfumes—in fact all the fields that the coal tar industry has developed in half a century.

Such is the prospect of usefulness which the future spreads before the cracking industry. But research and still more research is needed. The problem of producing high yields of gasoline from petroleum and other oils has been solved. The control of the cracking process to give maximum yield of the hydrocarbons of a given group, or to give a single desired hydrocarbon has been accomplished. The need now is for new methods of utilising the hydrocarbons made available, and new markets for the products which can be prepared from these substances. The cracking process has made possible the efficient utilisation of our petroleum resources and contributed tremendously to the stability of the automobile industry. It has the power to transform the whole scheme of hydrocarbon utilisation. It is an Aladdin's lamp, ready to accomplish new wonders when but touched by the magic of research.

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RÉSUMÉ

Le procédé moderne de cracking produit des débits élevés d'essence en partant d'une huile quelconque, soit-elle pétrole, goudron de houille à température basse, huile de schiste, bitume, goudron de bois, huile végétale, huile de poisson ou huile de tourbe. Les pays possédant de l'huile brute, de la houille ou du schiste bitumineux peuvent produire, de ces matériaux, du carburant de façon très efficace au moyen du procédé de cracking. L'huile brute sera probablement notre source dominante d'essence pendant un siècle à venir au moins.

Il est possible d'obtenir par cracking plus de deux fois la quantité d'essence qui peut être obtenue de l'huile brute au moyen de la distillation simple. L'essence produite par cracking est préferée à celle provenant de la distillation

ordinaire des huiles à cause de sa teneur en oléfine, naphtène et carbures aromatiques, qui lui donnent des qualités non-détonantes accusées. Le procédé de cracking a donné plus de 4.000.000.000 sur les 15.000.000.000 de gallons d'essence produits au cours de l'an 1927, et promet un approvisionnement de carburant suffisant pour des milliers d'années.

On peut effectuer le cracking par plusieurs méthodes. Dans le type de fonctionnement à huile résiduelle les produits sont de l'essence, de l'huile à four ou à moteur Diesel, du pétrole combustible de bonne qualité et du gaz. L'exploitation du type sans huile résiduelle donne de l'essence, de l'huile à four ou à moteur Diesel, du gaz et du coke. Les rendements d'essence produite par le cracking d'huiles lourdes par l'une ou l'autre de ces méthodes sont d'ordinaire de plus de cinquante pour cent de la charge. Dans encore une autre méthode d'exploitation, la production d'essence est secondaire et le but principal du cracking est d'abaisser la viscosité et l'épreuve à froid des huiles lourdes de sorte qu'elles puissent s'écouler facilement par les tuyaux.

Le procédé de cracking d'aujourd'hui est assez souple pour transformer une huile carbure quelconque et pour permettre une variation large dans les débits des différents produits pour convenir aux conditions économiques. Il peut s'employer pour produire des carbures d'une série désirée quelconque (paraffine, naphtène, oléfine, dioléfine, acétylène ou aromatique), ou même pour donner un rendement élevé d'un seul carbure. On a déjà préparé, des carbures crackés, un fort nombre de dérivés chimiques utiles. Un avenir riche est assuré à l'utilisation chimique plus étendue de ces corps, en particulier par rapport au caoutchouc et aux résines synthétiques.

Le cracking du goudron de basse température que l'on pourrait produire des gisements mondiaux connus de la houille grasse, de la houille demi-grasse et du lignite pourrait fournir plus de 1.000.000.000.000 de barils d'essence. En même temps seraient produit par la carbonisation de la houille à basse température et par le procédé de cracking, 3.350.000.000.000 de tonnes de coke et 2.300.000.000.000.000 de pieds cubes de gaz. On a cracké du goudron produit à basse température de la houille provenant de la Virginie de l'Ouest, de l'Ohio, de l'Indiana, de l'Utah et de la Virginie, et produit de lignite allemand, obtenant des rendements d'essence variant entre vingt-cinq et cinquante pour cent.

Beaucoup de pays possèdent de vastes gisements de schiste bitumineux On a cracké des huiles de schiste provenant des Etats-Unis, d'Ecosse, du Canada, de l'Australie, de France et d'Estonie, avec rendements de cinquante pour cent d'essence à peu près. Il existe de vastes dépôts de sables goudronneux, d'asphaltes et d'autres matériaux bitumineux que l'on pourrait cracker pour obtenir de bons rendements de carburant. Le cracking d'huile lourde de goudron provenant des sables goudronneux de l'Alberta (Canada) a donné trente-six pour cent d'essence.

Encore un corps que l'on peut cracker est le goudron de bois. On pourra sans doute rendre disponibles des goudrons de bois en grande quantité, puisqu'il est impossible d'employer plus de la moitié du bois de l'arbre ordinaire comme bois de charpente et que le reste est actuellement de rebut ou du bois de chauffage. Le cracking de goudrons de bois types a donné des débits d'essence de vingt-cinq pour cent à peu près.

Les huiles végétales telles qu'huile de palme, huile de coco et huile de coton, sont de bonnes huiles pour le cracking et seront utilisées sans doute comme

sources de carburant quand les conditions économiques rendront un tel emploi désirable. Elles donnent des rendements de plus de soixante pour cent.

Par la carbonisation de la tourbe on obtient une huile carbure qui donnerait assurément trente-cinq pour cent d'essence si on la crackait. Quelques pays pourront trouver économique le cracking d'huiles de poisson. Un essai de l'huile de Menhaden a produit plus de quarante-cinq pour cent d'essence.

CHEMICAL COMPOSITION OF POLISH NATURAL GASES AND THE DETERMINATION OF THEIR CALORIFIC VALUE

POLISH NATIONAL COMMITTEE, WORLD POWER CONFERENCE

*Paper No. F*13

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PART I. CHEMICAL COMPOSITION OF POLISH NATURAL GASES

Dr. K. Kling and L. Suchowiak

Natural gas is abundant throughout the entire area of the Polish oil fields situated in the Carpathian lowlands. As it is used practically solely as fuel for the production of power for the oil industry, analyses of the various combustible constituents present are of considerable interest. The following table gives analyses of samples of natural gases taken from various districts and wells. The Jaeger-Ubbelhode-Czako method of analysis, using mercury check devices, was employed.The hydrocarbons have been treated as a mixture of methane and ethane.

It can be seen from the table that the combustible part of the gas consists entirely of hydrocarbons, although in two samples from the Boryslaw region carbon monoxide was also detected. No traces

TABLE I.

Locality.	Well.	Owner.	CO_2	O_2	H_2	CO	CH_4	C_2H_6	N_2
Bitków ...	134	Dąbrowa	3·31	0·92	—	0·00	90·90	9·75	0·09
,, ...	Gusher ...	Nafta ...	3·80	1·94	—	0·00	85·19	5·30	3·76
Borysław	Bank 18 ...	Dąbrowa	1·52	0·03	—	0·00	70·69	27·76	0·00
,,	Tadeusz ...	Galicja ...	1·22	2·08	—	0·00	93·34		3·35
,,	Bank 19 ...	Dąbrowa	0·63	0·37	—	0·37	65·47	32·47	0·67
,, ...	Oleks 3 ...	,,	0·38	0·45	—	0·35	60·58	38·21	0·05
Męcinka	Michal 5 ...	Nafta Bor.	0·00	0·00	—	0·00	96·58		3·42
,,	Michal 2 ...	,,	0·00	0·00	—	0·00	96·58		3·62
Polanka	Gaz 6... ...	Zach. S-ka Naftowa ...	0·00	7·38	—	0·00	63·95		28·67
Krosno ...	Winnica 3 ...	Dąbrowa	0·70	0·00	—	0·00	95·66		3·64
,, ...	Krościenko 43	,,	1·90	0·00	—	0·00	96·80		1·30
,, ...	Krościenko 6	,,	0·63	0·00	—	0·00	96·34		3·03

of hydrogen were found. The non-combustible residue consists of carbon dioxide, oxygen and nitrogen.

A number of special analyses were also made in order to ascertain whether helium was present, and if so, to what extent. The results obtained showed that practically all of the natural gases from the Carpathian lowlands contain helium in very small quantities (not exceeding 0·05 per cent.). The helium was estimated by removing all other gases with activated charcoal cooled in liquid air, and measuring the residual pressure. The first series of experiments was carried out using an ordinary mercury gauge, but it was found that in some of the gases, particularly in those from the western part of the industrial area, the helium content was so low that a MacLeod gauge was necessary (Second series).

The results of these analyses are given in Table II.

TABLE II.

Series I.		Series II.	
Locality.	Percentage of Helium.	Locality.	Percentage of Helium.
Borysław ...	0·017	Polanka ...	0·0057
Borysław ...	0·011	Polanka ...	0·0084
Borysław ...	0·016	Krosno ...	0·0055
Borysław ...	0·014	Krosno ...	0·0069
Borysław ...	0·000	Krosno ...	0·0057
Borysław ...	0·000	Krosno ...	0·0062
Daszawa ...	0·017	Krosno ...	0·0034
Bitków	0·017	Borysław ...	0·0054
Bitków	0·021		
Bitków	0·016		

It can be seen that there is a definite distribution of helium which increases in an easterly direction.

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RÉSUMÉ

Les auteurs exposent les résultats des analyses du gaz souterrain provenant de diverses localités du bassin pétrolier polonais. Comme on voit des chiffres obtenus par eux, le gaz se compose presque entièrement d'hydrocarbures méthane et butane; les autres constituants, combustibles et incombustibles, ne forment que des quantités peu importantes.

D'autres recherches furent exécutées pour déterminer le pourcentage d'hélium dans le gaz en question. Les recherches ont démontré que le gaz souterrain en contient jusqu'au 0,017 pour cent.

PART II. DETERMINATION OF THE CALORIFIC VALUE OF NATURAL GAS FROM THE RELATIVE DENSITY

Dr. W. Dominik

The only methods available for the determination of the calorific value of natural gas, such as calorimetric and analytical methods, do not readily lend themselves to quick determinations at the actual source of supply. By means of the so-called "densoscope," described by Biluchowski and Kling,* it is, however, comparatively easy to ascertain the relative density of the issuing gas, and as natural gas consists almost entirely of paraffin hydrocarbons, the calorific value can be calculated from the density observed, provided that the gas is not in any way adulterated.

The apparent gravity of a paraffin molecule of the general formula $C_{n_1} H_{2n_1+2}$ is proportional to the index n_1. This ratio is defined by the discontinuous function

$$\gamma_w^1 = A^1 n_1 + a^1 \qquad (1)$$

where γ_w^1 is the apparent gravity of a paraffin molecule and A^1 and a^1 are constants common to all paraffins.

If we are dealing with a mixture containing homologous paraffins in quantities of x_1, $x_2 \ldots . x_r$ molecules, the apparent gravity can be expressed by

$$\Sigma\gamma_w^1 = A^1 (n_1 x_1 + n_2 x_2 + \ldots . n_r x_r) + a_1 (x_1 + x_2 + \ldots x_r) \qquad (2)$$

and the apparent gravity of the molecule is given by

$$\gamma_w^1 = A^1 \frac{n_1 x_1 + n_2 x_2 + \ldots n_r x_r}{x_1 + x_2 + \ldots . x_r} + a^1 \qquad (2a)$$

or in general $\gamma_w^1 = A^1 n + a^1 \qquad (2b).$

In view of the fact that the density of the gas is a function of the molecular gravity, the density of the hydrocarbon mixture under

*Metan, 1917, p. 13–16.

consideration can also be expressed by an equation analogous to (2b), as a constant linear function of the index n:

$$D = A\,n + a$$

where D = density of the paraffin mixture
A and a = constants corresponding to the above values A^1 and a^1
and n = index of the mixture.

This relationship is shown in Fig. 1, in which the relative density is plotted against the corresponding values for n.

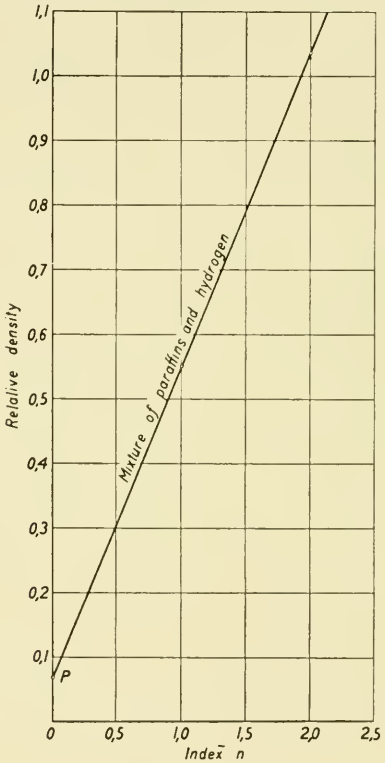

Fig. 1.

The possibility of expressing the density of a hydrocarbon mixture as a linear function of the index n leads to the supposition that other physical properties of the mixture can be expressed in an analogous manner providing that they are first-power functions of the individual homologues. Thus the calorific value can be expressed in calories per molecule by

$$W_g = K\,n + k \qquad (4)$$

where K and k are constants.

Combining equations (3) and (4), a relationship is obtained between the calorific value and the density of the mixture:—

$$W_g = \frac{K}{A} D + \left(k - \frac{K}{A} a\right) \quad (5).$$

Now the homologues of the series $C_n H_{2n+2}$ differ by one or more $\cdot C H_2$ groups so that the general formula for the series $C_n H_{2n+2}$ can be written as

$$H_2 + n\, C\, H_2 \quad (6).$$

When dealing with paraffin mixtures it must, however, be emphasised that in this formula the variable n is not integral, as it would be if the formula referred to an individual paraffin, but varies continuously from unity upwards.

As indicated by the formula, the calorific value of paraffins shows a constant increase and is proportional to the number of $\cdot C H_2$ groups present. From analogy between (4) and (6) the conclusion is reached that the factor K corresponds with the increase in the molecular heat from one homologue to the next. This increase, which corresponds with the increase in the calorific value, is approximately 158,000 calories.

The other factors in equation (6) have been determined experimentally and are as follows:—

K = 158,000 calories
k = 54,600 ,,
A = 0·485
a = 0·069

Assuming the average volume of one molecule to be 22·4 litres, the following equation is obtained:—

$$W_g = 14536\, D + 1437 \quad (7).$$

This formula applies to natural gas as a mixture of hydrocarbons. Actually, however, natural gas contains other gases which necessitate corrections being made to the relative density, the gas most frequently present being air. The calorific value may be obtained from the apparent relative density of the natural gas and from the percentage of air present by means of Fig. 2.

The point P corresponds with pure air and the line a-b with the paraffin mixture. The lines intersecting at P show the variation in the relative density with the percentage of air present, while the parallel lines indicate hydrocarbon mixtures corresponding with the percentages of air.

By drawing a straight line from the point determined by the relative density and the percentage of air present through P until it intersects the line a-b, it is also possible to find the calorific value of the hydrocarbons present.

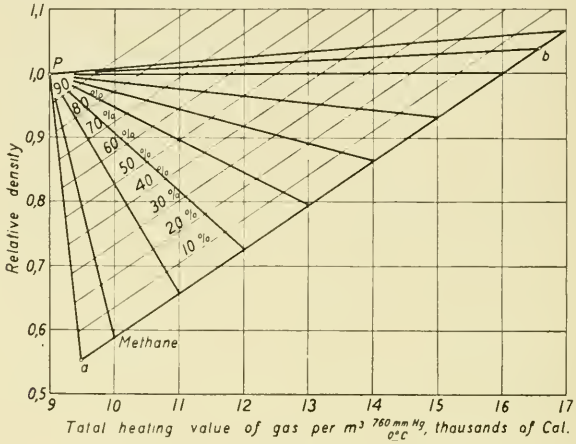

Fig. 2.

RÉSUMÉ

Après avoir signalé l'importance de la détermination de la puissance calorifique du gaz souterrain à l'endroit même de sa production, l'auteur souligne les avantages de la méthode densimétrique qui est la plus simple et, en même temps, bien exacte.

Il explique ensuite l'emploi de cette méthode, en se basant sur l'indice de l'hydrocarbure, c'est-à-dire sur le nombre n dans la formule générale $C_n H_{2n+2}$ (étant donné que les gaz souterrains polonais, comme d'autres, sont composés presque exclusivement du mélange d'hydrocarbures homologues du méthane). Les considérations de l'auteur sont complétées par un diagramme facilitant l'évaluation de la puissance calorifique d'après la mesure de la densité relative du gaz.

Un autre diagramme a pour but d'introduire la correction concernant la présence d'air dans le gaz.

PART III. DETERMINATION OF THE CALORIFIC VALUE OF NATURAL GAS BY MEANS OF CHEMICAL ANALYSIS

W. Lesniański and K. Katz

The determination of the calorific value of a natural gas by the usual methods of calorimetric analysis, is often rendered difficult by the smallness of the sample available. In such instances a method of calculating the calorific value from the chemical composition should prove useful. Such a method is described below.

As the main constituents of natural gases are paraffins, the easiest method of calculating the calorific value W_g from the analysis is

to make use of the relationship which exists between W_g and the index n of the hydrocarbon mixture in the general formula $C_n H_{2n+2}$ This relationship is given by the equation

$$W_g = K n + k \qquad (1)$$

where K and k are constants common to all paraffins.

The index for the mixture can be obtained from the equation of combustion

$$C_n H_{2n+2} + \frac{3n+1}{2} O_2 = n CO_2 + (n+1) H_2 O$$

from which it follows that

$$n = \frac{\text{volume of carbon dioxide}}{\text{volume of hydrocarbon mixture}} \cdot \frac{V_\zeta}{V_x} \qquad (2)$$

where V_ζ = volume per mole. of hydrocarbon mixture
and V_x = volume per mole. of carbon dioxide.

If, in addition to paraffins the gas contains other combustible components such as carbon monoxide (η per cent.) and hydrogen (χ per cent.), the equation must be modified as follows:—

$$W_g = \frac{K n + k}{V_\zeta} \cdot \frac{\zeta}{100} + \frac{W_\eta}{V_\eta} \cdot \frac{\eta}{100} + \frac{W_\chi}{V_\chi} \cdot \frac{\chi}{100} \qquad (3).$$

Assuming that $n = \frac{x^1}{\zeta} \cdot \frac{V_\zeta}{V_x}$

where x^1 is the quantity of carbon dioxide produced in burning G litres of hydrocarbon mixture, the equation becomes

$$W_g = \frac{K}{100\, V_{x^1}} x^1 + k \cdot \frac{\zeta}{100\, V_\zeta} + \frac{W_\eta}{V_\eta} \cdot \frac{\eta}{100} + \frac{W_\chi}{V_\chi} \cdot \frac{\chi}{100} \qquad (3a).$$

The constants K and k can be found from Thomsen's figures for the calorific values of the paraffins. K represents the average increase in the calorific value from one paraffin to the next higher homologue, and under normal conditions is 158,623 calories. The factor k represents the difference between the calorific value for methane and the average increase factor K. Actually k is 53,307 calories. Other factors having constant values are

$W_\eta = 67{,}960$ $\qquad$ $V_\eta = 22{\cdot}293$
$W_\chi = 68{,}360$ $\qquad$ $V_\chi = 22{\cdot}429$
$\qquad\qquad\qquad\quad$ $V_x = 22{\cdot}258$

The volume of a molecule of the paraffin mixture can be expressed as a function of the ratio $\frac{x^1}{\zeta}$ so that

$$V = 22{,}258 - 0{\cdot}203 \frac{x^1}{\zeta} \qquad (4)$$

$$\text{or } \frac{1}{V} = 0{\cdot}0004615\,\frac{x^1}{\zeta} + 0{\cdot}0442688 \qquad (4a).$$

Substituting these values in the equation (3a), the following equation for the total calorific value of natural gas in calories per litre is obtained:—

$$W_g = 71,512x^1 + 23\ 598\,\zeta + 30\ 48\chi + 30\ 35\ \eta \qquad (5).$$

The equation for the net calorific value is similar in appearance. The latent heat of vaporisation of the water produced from the paraffins is given by

$$Q = \frac{(n+1)\,\zeta}{V_\zeta} \cdot q$$

where q = heat of vaporisation of 1 mole. of water (10,710 calories).

Subtracting (6) from (3), we obtain

$$W_d = \frac{K-q}{100\,V_{x^1}} \cdot x^1 + \frac{k-q}{100\,V} \cdot \zeta + \frac{W_\eta}{V_\eta} \cdot \frac{\eta}{100} + \frac{W_\chi}{V_\chi} \cdot \frac{\chi}{100} \qquad (7)$$

where W_χ is the calorific value per mole. of hydrogen. By applying the value of the factors the equation for the net calorific value becomes

$$W_d = 66,651\,x^1 + 18,857\,\zeta + 2571\,\chi + 3035\,\eta \qquad (8).$$

Actually the calorific values of the three lowest paraffins, calculated by means of these formulæ, differ from the experimental figures of Thomsen by a maximum of 17·4 calories. Results obtained for natural gas by the Junkers' apparatus and by the above method have shown that the method is sufficiently accurate for most purposes, the error being $\leqslant 1$ per cent. Compared with the calorimetric method it is much simpler and, as stated above, requires much less material for determinations.

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RÉSUMÉ

Les auteurs attirent l'attention sur ce qu'il est souvent difficile d'employer la méthode calorimétrique de la détermination de la puissance calorifique du gaz fossile, la quantité du gaz à l'épreuve étant insuffisante. Dans ce cas, la méthode basée sur l'analyse chimique est bien plus aventageuse.

Etant donné que les gaz souterrains sont composés des hydrocarbures homologues du méthane, c'est-à-dire qu'ils peuvent être représentés par la formule générale C_nH_{2n+2}, et que leurs propriétés physiques varient avec

la valeur de l'indice n de cette formule, les auteurs donnent la formule exprimant la puissance calorifique du gaz en fonction de l'indice n.

En considérant ensuite les mélanges des gaz contenant non seulement les hydrocarbures parafineux, mais aussi d'autres constituants combustibles, comme l'oxygène et l'hydrogène, ils exposent les formules de la puissance calorifique théorique et utile en fonction du pourcentage des divers constituants du gaz.

PART IV. A COMPARISON OF THE METHODS FOR DETERMINING THE CALORIFIC VALUE OF NATURAL GAS

J. Wójcicki

The purpose of this research was to compare the direct (calorimetric) and indirect methods of determining the calorific value of natural gas, particularly with respect to accuracy, suitability of apparatus, time required, etc.

Comparative determinations were made at the actual source of the gas in the oil well district at Boryslaw and Tustanowice and at Daszawa. The gases used were obtained either from wells producing gas exclusively or from wells yielding oil and gas simultaneously; they contained an appreciable amount of gasoline ("moist gas"). The calorific value of the gases varied from approximately 10,000 to 17,000 calories per litre at 15°C. and 735 mm.

All calculations were based on the assumption that the combustible portion consisted of paraffin hydrocarbons of the general formula $C_n H_{2n+2}$.

Direct Method.

Two types of calorimeters were employed for the direct determinations, the Junkers' and the "Union."

Considerable difficulty was experienced in using the Junkers' apparatus owing to the high calorific value of the gas, which resulted in incomplete combustion taking place. By reducing the "load" of the burner to 10-17 calories per minute, the losses due to unburnt gas were reduced to between 1·5 and 7·5 per cent., the losses being determined by collateral analyses of the combustion products. After making allowances for these losses, the figures obtained were sufficiently reliable to be used as standards in estimating the accuracy of other methods.

The values obtained for the condensed water were consistently low when compared with the theoretical values, calculated on the index n, and assuming that only paraffins were present. By allowing for the unburnt hydrocarbons and the difference in the humidity

of the air supplied for combustion and of the combustion products themselves, the error in the condensed water value was reduced to less than 1 per cent. The corrected value was then used as a basis for determining the net calorific value of the gas. It was found, however, that the net calorific value could be determined with sufficient accuracy by making use of the relationship existing between the net and the total calorific values of paraffin hydrocarbons expressed in the equation (Fig. 1):—

$$W_n = B\,W_g + b$$

where B and b are constants and W_g and W_d are the net and total calorific values of the gas respectively.

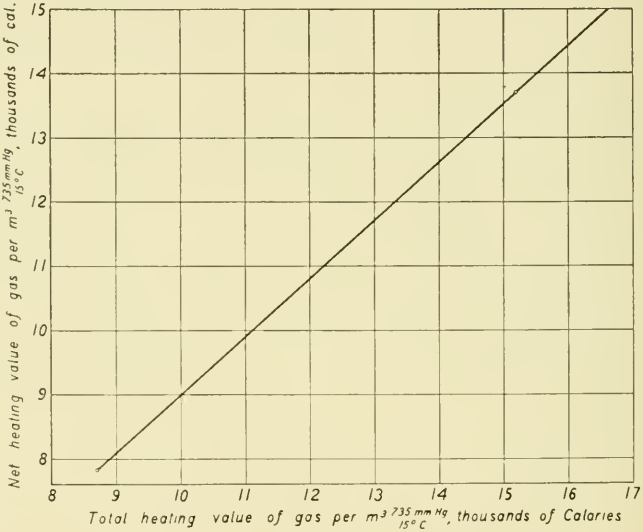

Fig. 1.

The use of this equation dispenses with the necessity for measuring the condensed water.

Parallel determinations carried out by means of the "Union" calorimeter showed differences amounting to as much as 32 per cent. These discrepancies were due to the fact that part of the natural gas in the container escaped combustion, a fact which could be ascertained by observing the height of the flame. Even when the approximate correction obtained by estimating the quantity of gas which passes through the flame was applied, the differences were between 7 and 12 per cent. This seems to indicate that even part of the gas passing through the flame escapes combustion.

INDIRECT METHODS

Of the two indirect methods available for the determination of the calorific value of natural gas, *viz.* (1) by observing the relative density of the gas and (2) by determining the index n of the hydrocarbon mixture by chemical analysis, only the latter was found to give results which compared with the Junkers' calorimetric value and were accurate to within 1 per cent.

The relative densities were obtained by means of a Bunsen densoscope and were corrected for foreign gases, *i.e.*, carbon dioxide and air. The index n was determined from the amount of carbon dioxide produced on combustion of the gas in a combined Orsat apparatus and a Hempel burette fitted with a platinum tube and using mercury checking devices. For purposes of control, n was also calculated from the reduction in volume and the quantity of oxygen used during the combustion.

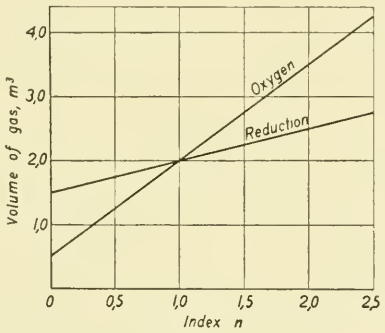

Fig. 2.

Both the apparent density and the index n were found for average samples of gas taken from the aspirator attached to the Junkers' calorimeter, so that all the results were strictly comparable.

From the equations:

$$D = 0{\cdot}485\,n + 0{\cdot}069 \quad (2)$$

$$\text{and } W_g = 6500\,n + 2200 \quad (3)$$

$$\text{we obtain } W_g = 13154\,D + 1214 \quad (4)$$

where D = relative density of the natural gas

n = index in the general formula $C_n H_{2n+2}$ for the hydrocarbon mixture

and W_g = total calorific value (in calories per litre at 15°C. and 760 mm.).

It was found from the results obtained that this relationship only holds for gases of low calorific value. Thus, for a natural gas having a relative density over 0·7 (after correcting for air, etc.) errors up to

13 per cent. were observed. These errors are given by the equation:

$$\Delta_w = 7375{\cdot}3\,D - 5301{\cdot}3 \qquad (5).$$

The curve for the actual calorific value, plotted as a function of the relative density, agrees with the relationship expressed by formula (4) until the density reaches approximately 0·7, above which it is expressed by the equation:

$$W_g = 13514\,D + 1214 + \Delta_w \qquad (6)$$

On substitution for Δ_w this becomes

$$W_g = 20889{\cdot}3\,D - 4087{\cdot}3 \qquad (6a).$$

These relationships are shown in Fig. 3.

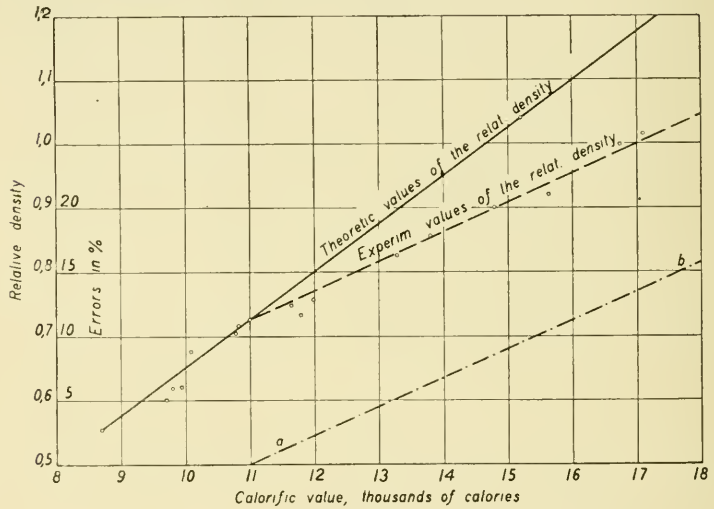

Fig. 3.

General Conclusions

For the sake of clearness the results of the various tests have been given in tabular form (Fig. 4).

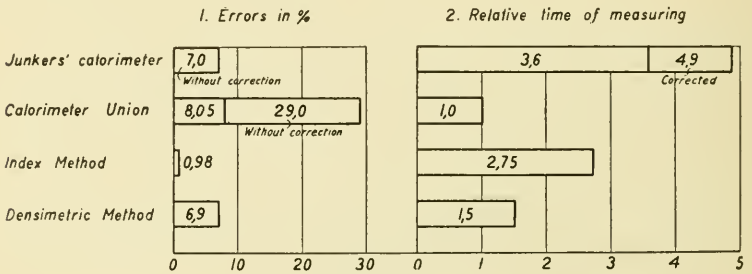

Fig. 4.

Relative errors are expressed as a percentage of the calorific value determined by the Junkers' calorimeter and the time required for each determination is compared with the time required when using the "Union" calorimeter.

The "Union" calorimeter requires the shortest time, but on account of its low accuracy, even after corrections have been made, the results are not of great value. The Junkers' calorimeter, without corrections for unburnt gas and the indirect method, using the relative density, give, so far as accuracy is concerned, practically identical results, the error generally amounting to 7 per cent. By applying corrections to the equation for the total calorific value, the results very closely resemble the real values. In spite of this, the densometric method can only be regarded as a rough method of determining calorific value.

The most accurate results were obtained by the second indirect method employing chemical analysis to determine the hydrocarbon index n. Not only are the results better than, or comparable with, those obtained by the direct method, but the determinations require only half the time.

RÉSUMÉ

L'auteur examine les méthodes, actuellement en usage, de la détermination de la puissance calorifique du gaz souterrain, notamment la méthode directe (calorimétrique) et les méthodes indirectes (densimétrique et chimique). D'après de nombreux essais executés par lui, les resultats desquels sont présentés dans les diagrammes des erreurs relatifs à diverses méthodes, l'auteur exprime la conclusion qu'en ce qui concerne le temps nécessaire à l'essai, la méthode calorimétrique, et particulièrement l'emploi du calorimètre "Union," est la plus convenable. D'autre part, l'erreur resultant de cette méthode, même après l'introduction de la correction, est si importante qu'on ne peut pas faire usage de cet appareil. Le calorimètre Junkers et la méthode densimétrique donnent des résultats de même exactitude (erreur moyenne de 7 pour cent, sans correction), mais eux non plus ne peuvent être considérés comme méthodes assez exactes. Au contraire, la méthode chimique, basée sur l'analyse et sur la détermination de l'indice n du mélange des hydrocarbures C_nH_{2n+2}, peut être nommée exacte. De plus, elle exige presque deux fois moins de temps que les méthodes calorimétriques de même exactitude.

GENERAL REPORT ON SECTION F

COMPOSITION, CLASSIFICATION, PREPARATION, STORAGE AND HANDLING OF LIQUID FUELS

DR. A. E. DUNSTAN

The General Report covers the twelve papers comprising Section F. (Composition, Classification, Preparation, Storage, and Handling of Liquid Fuels), *viz.*,

1. "The Characteristics of Motor Spirit." (Austria.)
Authoritative Body: Gesellschaft für Wärmewirtschaft.

2. "The Availability of the Alberta Bituminous Sands for Production of Fuel Oil." (Canada.)
Authoritative Body: Scientific and Industrial Research Council of Alberta. Author: K. A. Clark.

3. "Properties required of Liquid Fuels for use in Automobile and Aircraft Engines, and how the Oil Industry meets these Requirements." (Germany.)
Authoritative Body: Automobil- und Flugtechnische, Berlin, und Benzol-Verband, Bochum. Author: Wa. Ostwald.

4. "Recent Developments in the Distillation of Petroleum." (Great Britain.)
Authoritative Body: The Institution of Petroleum Technologists. Authors: Dr. A. E. Dunstan and Dr. S. F. Birch.

5. "Chemical Reactions involved in the Refining of Petroleum." (Great Britain.)
Authoritative Body: The Institution of Petroleum Technologists. Authors: Dr. S. F. Birch and Dr. W. S. Norris.

6. "The Composition and Chemical Properties of Russian Oils." (Russia.)
Authoritative Body: Russian National Committee, World Power Conference. Author: Prof. J. Elin.

7. "Investigations in Distilling Processes of Swedish Oil Shales." (Sweden.)
Authoritative Body: Swedish National Committee, World Power Conference. Author: B. Holmberg.

8. "Recent Advances in Cracking." (Great Britain.)
Authoritative Body: The Institution of Petroleum Technologists. Authors: Dr. A. E. Dunstan and R. Pitkethly.

10. "The Technical Aspects of the Storage, Handling and Transmission of Liquid Fuels by the User."
Authoritative Body: Technical Committee, Fuel Conference, 1928. Author: I. Lubbock.

11. "Shale and the Production of Oil from Shale." (U.S.A.)
Authoritative Body: U.S. Bureau of Mines. Author: Harry H. Hill.

12. "The Cracking Process—A Universal Source of Motor Fuel." (U.S.A.)
Authoritative Body: U.S. Bureau of Mines and American Institute of Mining and Metallurgical Engineers. Author: Dr. G. Egloff.

13. "Chemical Composition of Polish Natural Gases and the Determination of their Calorific Value." (Poland.)
Authoritative Body: Polish National Committee, World Power Conference. Authors: Dr. K. Kling, L. Suchowiak, W. Lesnianski, K. Katz, Dr. W. Dominik, and J. Wojcicki.

These papers may, for the purpose of this General Report, be classified under the following headings:—

1. Recent advances in cracking.
2. The characteristics of motor spirit.
3. Refining.
4. The composition and chemical properties of Russian oils.
5. Chemical composition of Polish natural gases and the determination of their calorific value.
6. The technical aspects of the storage, handling and transmission of liquid fuels by the user.
7. Recent developments in the distillation of petroleum.
8. Oil shales.
9. Properties required of liquid fuels for use in automobile and aircraft engines and how the oil industry meets these requirements.
10. The availability of the Alberta bituminous sands for the production of fuel oil.

(*i*) *Recent Advances in Cracking*

Without doubt the greatest advance made within the petroleum industry during recent years is the development of the modern

cracking process and this development has occurred almost entirely in America, where the necessity of supplementing straight run gasolene first became evident. Although vapour phase processes were first in the field, full development of this type of cracking was abandoned in favour of liquid phase processes on account of the practical advantages of the latter. By liquid phase cracking is now manufactured the immense quantity of cracked gasolene. This extra production has allowed the rapid development of motor transport and has been the most effective step towards conservation of petroleum resources.

The difficulties encountered in the development of modern cracking units have been largely overcome. Fuel economy has been effected by improvements in furnace construction, recirculation of flue gases, preheating air supply and the use of hot oil pumps. Standardisation of construction, automatic control and improved instruments have all helped to lower working costs and to improve operating conditions. Commercially successful processes have the same essentials of simplicity of design and operation and they rely on heat treatment only to effect cracking, hence heating coils and reaction chambers are generally used.

Knowledge of the physical and chemical effects of cracking has also advanced within the last few years as temperature, pressure and time effects have been investigated for certain oils, and the application of various refining agents has been studied. Vapour phase cracking has received more interest lately on account of the high anti-knock properties of the gasolene, although this is only one of its peculiarities.

Brief descriptions of the best known vapour phase commercial processes and the most recent developments in the established liquid phase processes are given and results are recorded for the cracking of petroleum, coal tar, peat tar, shale oil, wood tar, vegetable and fish oils.

The primary use of the cracking process up to the present time has been the conversion of hydrocarbon oils into motor fuels. But tremendous as this achievement is, it does not represent the full possibilities of cracking. The cracking process can convert any liquid carbonaceous material into practically any hydrocarbon product. From these a host of other materials can be obtained, including alcohols, glycols, paint thinners, solvent oils and lubricating oils, made from the cracked oils and asphalt from the residuum by oxidation.

But the flexibility of the cracking process does not stop with even this list of products. The cracking operation can be so controlled as to give maximum yields of the hydrocarbons of any desired series, or even to give a large yield of a single hydrocarbon. The products of cracking include hydrocarbons of all series, paraffins, naphthenes, olefines, diolefines, acetylenes and aromatics. By this production of hydrocarbons of the most varied sorts the cracking process opens the door to the but partially explored field of the chemical by-products of petroleum.

The paraffin hydrocarbons have as yet found use principally as fuel. They make up a large proportion of cracked products. The lower ones are readily obtainable in pure form and at the present time possess but limited utility because they are undesirable in gasolene. Work is urgently needed to develop means for converting these substances into useful derivatives. Of the naphthene series, individual members may now be produced by cracking, and no doubt uses will be found to which they are exactly suited.

The olefines, being reactive substances, have many more uses than the paraffins or naphthenes. By proper regulation of the cracking process, any desired member of this series may be produced, such as ethylene, propylene, the butylenes, etc. Their utilisation is an immense and promising field. By chlorination these hydrocarbons may be made into valuable solvents. They can also readily be converted into alcohols, certain of which, as ethyl and isopropyl alcohols, and several glycols have already been produced on a commercial scale, while many others have been made in the laboratory. Those which are now but curiosities will no doubt prove useful in the future. The olefines should also be convertible into fatty acids and soaps.

The diolefines, also present in cracked products, are other substances of great potential value. Of this series, butadiene has already been isolated. Being closely related to the rubber hydrocarbons, the diolefines may well serve as starting materials for the successful production of synthetic rubber. Likewise they can be polymerised into resins, which are usable as insulating material and may find employment in other of the multitudinous uses to which the familiar aldehyde-phenol type resins have been put. They should also be of value as lacquer and varnish bases.

(*ii*) *The Characteristics of Motor Spirit*

A specification on specific gravity alone has been found to give

little indication of quality and the peculiarities which manifest themselves during combustion.

Numerous experiments by the "Gesellschaft für Wärmewirtschaft," in conjunction with producers, factors and consumers of motor spirit, have led to various useful conclusions and suggestions.

Although the fractional distillation curves give a truer indication of the characteristics, it is necessary at the same time to quote the specific gravity, as variation from heavy to light grades give rise to trouble with the setting of the carburettor float.

To comply with the various requirements of the trade, three methods of characterisation have been decided on, details of which will be found in the original.

(*iii*) *Refining*

To meet public demand modern petroleum products, especially light distillates, are more highly refined than is necessary from a purely utilitarian point of view. This is wasteful in time and material. There is to-day a widespread tendency to revise standards of refining and to reduce treatments to the necessary minimum.

Soda-washing of light distillates removes hydrogen sulphide completely and mercaptans partly. The readiness with which hydrogen sulphide undergoes atmospheric oxidation to elementary sulphur makes its removal at the earliest stage imperative; the ease with which it is removed by means of soda is therefore fortunate. A given weight of soda is more effective for removing mercaptans the greater the dilution at which it is employed. Free sulphur reacts with sodium sulphide (derived from hydrogen sulphide) to give polysulphides which oxidise mercaptans to disulphides; these pass back into the oil. Sodium sulphide also reacts with a further quantity of hydrogen sulphide to give sodium hydrogen sulphide. The reaction is reversed and the mono-sulphide recovered for further use by air-blowing. Spent soda may thus be employed to remove hydrogen sulphide from natural gas. Lime may be employed in place of sodium hydroxide. Sodium carbonate solution is employed to wash distillates which have received an acid or sulphur dioxide treatment.

Sodium plumbite solution is generally used, following a soda-wash, to sweeten an oil which contains mercaptans. The latter are converted to lead mercaptides, which are, in part, oil soluble, and are incompletely precipitated. Addition of free sulphur completes the treatment, lead mercaptides being converted into insoluble lead sulphide

and oil-soluble disulphides. Any desulphurisation which occurs is due to adsorption of sulphur compounds on the lead sulphide. In lead sulphide refining, sulphur compounds adsorbed on lead sulphide are oxidised by air-blowing, whereby sweetening is accomplished.

Aqueous alkali or alkaline-earth hypochlorite solution oxidises organic sulphides to sulphones, disulphides to sulphonic acids, mercaptans first to disulphides and then to sulphonic acids. Hydrogen sulphide would be oxidised to free sulphur, but this is avoided by giving a preliminary soda wash. Excess of alkali stabilises the hypochlorite solution and retards the oxidation of sulphur compounds. If sufficient alkali is present the oxidation of a mercaptan may stop at the disulphide; sweetening will thus be effected without desulphurisation, the reagent being comparable with plumbite when used with the addition of elementary sulphur. Alkaline hypochlorite solutions may be used for sweetening cracked distillates.

Sulphuric acid has a general solvent action on sulphur compounds dissolved in a petroleum distillate. Mercaptans are oxidised to disulphides, which are dissolved in the acid. Sulphonation of aromatic hydrocarbons occurs. Basic substances are removed as salts. Sulphuric acid acts as a polymerising agent for the more reactive constituents of a cracked distillate. Some of the products are removed in solution, some remain as a residue when the acid-treated oil is redistilled and some pass into the distillate as stable, fairly volatile polymerides. Diolefines form acid-soluble tars. Some of the olefines give alcohols or their esters. The action of sulphuric acid is greatly dependent on the concentration and temperature at which it is used.

Aqueous cuprammonium sulphate is said to remove mercaptans, disulphides, acetylenes and diolefines.

Aromatic or unsaturated hydrocarbons are much more soluble than paraffins or *cyclo*paraffins in liquid sulphur dioxide. Additive compounds of sulphur dioxide with aromatic hydrocarbons are known, but the main action is a purely solvent one. Edeleanu's liquid sulphur dioxide process, based on these facts, was originally designed to remove unsaturated and/or aromatic constituents that cause Roumanian kerosene to burn with a smoky flame. For practical reasons the extraction of kerosene is carried out at a temperature (15°-30° F.) much above that which gives the best separation; the partial separation which results gives an extract which is a valuable source of anti-detonating fuel. Owing to preferential solubility a partial desulphurisation is also effected.

Anhydrous aluminium and zinc chlorides act as energetic polymerising agent for unsaturated hydrocarbons even at ordinary temperatures, whilst at high temperatures (*e.g.*, 120°C.) they act as desulphurising agents; sulphur compounds are decomposed to give others which may be dealt with subsequently by means of sodium plumbite (*q.v.*). Bauxite, roasted at 400°-500°C., is a desulphurising and decolourising agent for liquid kerosene. The action is one of adsorption, but oxidation of sulphur compounds by adsorbed oxygen also plays a part, the resulting compounds being more readily retained by the bauxite. Bauxite also acts as a polymerising agent for the gum-forming constituents of cracked distillates. The action of silica gel in desulphurisation and decolourisation is probably similar to that of bauxite. Fuller's earth and floridin are used as filtration media to remove colour from light distillates; they are also employed as polymerising agents for treating cracked distillates in the vapour phase.

(iv) The Composition and Chemical Properties of Russian Oils

An exhaustive study of the composition of petroleum offers great difficulties on account of its extreme complexity and the inactive nature of the hydrocarbons of which it is composed.

The petroleums from the principal Russian oil-fields, for instance those from the Baku oil-fields, are generally classified as "naphthenic oils," as distinct from the American oils, for example, the Pennsylvanian oils, which are referred to as "paraffinic." To classify Russian oils as naphthenic is only partly correct, for, although naphthenes predominate in the lightest fractions from the Baku oils, paraffin hydrocarbons are also present.

The principal Russian oil-fields, which lie on the flanks of the Caucasus mountains near the towns of Baku and Grozny, give roughly 95 to 97 per cent. of the total Russian production. The crude oils from these fields can, with few exceptions, be classified as mixed-base oils. All contain wax, some in almost infinitesimal quantities, and most have a considerable, sometimes very large, percentage of gummy and asphaltic substances, low acidity, small sulphur content, low percentage of unsaturated hydrocarbons as well as wax—rendering it possible to prepare lubricating oils ranging from middle lubricating oils to bright cylinder oils from the residuum. They are obtained by distillation using a slight vacuum and introducing large quantities of super-heated steam; the distillates need little treatment.

(v) *Chemical Composition of Polish Natural Gases and the Determination of their Calorific Value*

PART I

Natural gas is abundant throughout the entire area of the Polish oil-fields situated in the Carpathian lowlands. As it is used practically solely as fuel for the production of power for the oil industry, analyses of the various combustible constituents present are of considerable interest.

PART II

The only methods available for the determination of the calorific value of natural gas, such as calorimetric and analytical methods, do not readily lend themselves to quick determination at the actual source of supply. By means of the so-called "densoscope," described by Biluchowski and Kling, it is, however, comparatively easy to ascertain the relative density of the issuing gas, and as natural gas consists almost entirely of paraffin hydrocarbons, the calorific value can be calculated from the density observed, provided that the gas is not in any way adulterated.

PART III

The determination of the calorific value of a natural gas by the usual methods of calorimetric analysis, is often rendered difficult by the smallness of the sample available. In such instances a method of calculating the calorific value from the chemical composition should prove useful. A suitable method is described.

(vi) *The Technical Aspects of the Storage, Handling, and Transmission of Liquid Fuels by the User*

This paper gives first-hand and very valuable information on the grades of fuel oil commonly used, with their physical and chemical characteristics, storage tanks and a typical user's installation, the means of heating fuel oil, filtration, transmission and pumping.

(vii) *Recent Developments in the Distillation of Petroleum*

The modern aspect of distillation by means of pipestills and fractionating "bubble" towers are described. Straight distillation of crude, as well as the fractionation of the less volatile components of natural gas and of lubricating oil are dealt with.

Modern pipe heaters are described in some detail, and the methods of control adopted in current practice are outlined.

(viii) Oil Shales

Two papers are presented on this subject and deal with Swedish and American material. The former gives details of the chemical examination of the fractions of the crude and the application thereof, with an account of the organic compounds occurring in the shale.

The Bureau of Mines contribution describes the experimental shale oil plant established under its auspices in Colorado and discusses the oil shale resources of the United States, the characteristics of American oil shale and its products, American oil shale developments, technical and economic problems of the industry and a future programme of work.

(ix) *Properties Required of Liquid Fuels for use in Automobile and Aircraft Engines and how the Oil Industry meets these Requirements*

At the present time the substances employed as fuels for internal combustion engines include hydrocarbons, alcohols, and certain organic compounds.

A convenient method of expressing the value of a fuel, however, is by means of the "energy-volume," that is the volume of fuel required to furnish a definite amount of energy.

The essential features of a fuel for automotive engines are low cost and high ton-mileage, and, to secure the former, thermal efficiency is often sacrificed. The wide range of uses to which such fuels are put, from driving private cars to driving lorries or fishing boats, indicates that two types of fuel are really necessary, one a "luxury" fuel and the other a "useful" fuel. While the chief requirements of the former include easy starting, rapid acceleration, clean burning and absence of odour both before and after combustion, those of the latter are cheapness and high ton-mileage.

Fuel development and engine design have influenced each other. For example, the constant-volume cycle engine has been improved by increasing the compression ratio, this being rendered possible by the production of fuels stable to high compression, such as aromatic, naphthenic or alcoholic fuels. "Anti-knocking" agents have also been developed for increasing the stability of fuels towards high compression. On the other hand, the advent of the high-speed Diesel engine has resulted in lower compression ratios being used and also in a considerable decrease in engine weight. For this type of engine, the aliphatic fuels are preferred, on account of their low spontaneous ignition temperatures or "pro-knocking" tendencies.

Amongst the general properties of liquid fuels are discussed:—

Corrosive action.
Stability.
Freedom from dirt and water.
Odour.
Toxicity.
Tendency to dissolve varnish, etc.
Miscibility.
Stability to low temperatures.
Sensitivity to water.

Production and Supply of Fuels

Benzole is so plentiful in Germany that it is used both alone and mixed with benzine; as a result German automobile engines tend to have comparatively high compression ratios. In the U.S.A. the total benzole production forms only a fraction of the motor fuel consumption so that American car builders can only increase the compression ratio of their engines as better fuels become available. The net result is that the compression ratios of German automobile engines are higher than elsewhere.

Unimportant characteristics of fuels are discussed, *e.g.*, specific gravity, colour and stability to light.

The three properties of a fuel which determine its value are: (*a*) volatility, (*b*) purity and (*c*) combustion characteristics.

Proposed Specifications. Fuel requirements have become so definite that it is possible to select a small number of fuels as standards and specify their essential characteristic. The suggested fuels are:

(*a*) Fuels of high volatility (Gasoline)
  (1) Low anti-knock value.
  (2) Medium anti-knock value.
  (3) High anti-knock value.
(*b*) Special fuels of medium volatility for aircraft.
(*c*) Fuels of low volatility. (Diesel oils.)
  (1) Relatively low boiling range.
  (2) High boiling range.

The following properties to be standardised:

(*a*) Volatility. (Average boiling point, fractionation index.)
(*b*) Purity.
(*c*) Compression stability (the standard and measurement to be specified).

(*d*) Stability on storage.
(*e*) Freedom from corrosive action.
(*f*) Sulphur content.
(*g*) H/C ratio.
(*h*) Odour.
(*i*) Stability to cold.

(*x*) *The Availability of the Alberta Bituminous Sands for the Production of Fuel Oil*

The purpose of this paper is to give, very briefly, a statement of the information now available regarding the bituminous sands of Alberta and their potentialities as a source of liquid fuel. Increasingly frequent reference is being made to this occurrence in discussions of the sources of liquid fuel throughout the British Empire and the World.

DISCUSSION

TUESDAY, SEPTEMBER 25 (AFTERNOON)

Section F

COMPOSITION, CLASSIFICATION, PREPARATION, STORAGE, AND HANDLING OF LIQUID FUELS

Chairman: SIR THOMAS HOLLAND, F.R.S.

THE CHAIRMAN, extending a hearty welcome to the delegates, said that at the Conference Banquet on the previous evening, a good deal had been heard about the bringing together of representatives of all nations to discuss their mutual problems, and of its influence for international peace. There was one point, however, which had been overlooked, namely, that we did not want merely the peace which resulted from our becoming friendly with one another; that was the kind of peace which never lasted. We wanted a peace which was based on economic considerations. In the early days of civilisation, when people first began to settle down, people were agricultural in their outlook, and boundary lines were fixed by agricultural considerations. In the course of the ages minerals had become an important consideration in the wealth and industrial development of every country, and it was found that the political boundaries laid down in accordance with agricultural considerations did not coincide with the political boundaries we should like, in view of the development of mineral processes. Inasmuch as the position of mineral deposits could not be moved, the various countries had to be at peace with one another, because one country possessed minerals which another country must share. That was why we were willing and anxious to lay the foundations of a peace that was permanent, and based on economic considerations.

DR. A. E. DUNSTAN (Vice-Chairman and General Reporter of the Section, Great Britain) presented his General Report.

DR. G. EGLOFF (U.S.A.), after emphasising that all the potentialities of the cracking process were not yet in sight, discussed the position with regard to future supplies of liquid fuels. He had made a calculation which should serve to stop the bleatings of the dismal prophets who were predicting that we should be out of motor fuel in a few years. As recently as two years ago a warning had come out of Washington that in six years time we should be practically at the end of our oil resources, and that every effort ought to be made to conserve gasoline. If there was one idiotic idea running through the world, it was that. The deposits of hydrocarbonaceous materials throughout the world were such that there was enough potential motor fuel to supply the world's needs for 3,000 years,

with the aid of the cracking process. Coal shale, wood tars, vegetable oils, peat tars and fish oil, which contained no gasoline as such, could be converted by heat and pressure to yield gasoline to the extent of 50 per cent. or more. At present about 30 million motor cars were in use in the world. In the past ten years there had been an annual increase of about 10 per cent., and if that increase were maintained there would be about 75 million motor cars in operation in 1938, and the world's annual requirements of gasoline would increase from the present figure of 16 billion (16 thousand million) gallons to something like 40 billion gallons. We need have no fear as to the supplies to meet that need. From time to time it had been stated that there was a shortage of rubber. In the cracking process, however, there were produced substances such as butadyene, from which a rubber-like material could be made, and the quantity produced was sufficient to provide all the automobile tyres needed in the world to-day. In his judgment, nations such as Great Britain, France, Germany and Italy, which had no crude oil supplies, should install cracking units, not only for use in peace time, but also to provide for their needs should emergency arise. They would then be able to crack low-priced fuel oil into gasoline to the extent of 50 per cent. or more. He suggested that they should construct concrete tanks in various parts of their areas sufficient to hold in the aggregate from 100 to 300 million barrels of fuel oil, purchase fuel oil in the open market, and store it as cracking stock in order to meet any emergency that might arise. It might be said that 100 million barrels of fuel oil was a large quantity, but it was common practice for the United States to have over 600 million barrels of oil in storage. A quantity of 100 million barrels in France would be sufficient to provide a five years' supply of gasoline, at the present rate of consumption. Moreover, in times of stress or national emergency the cracking process could be so controlled that it could produce, from the hydrocarbonaceous material on hand, substances such as benzol and toluol, which were the two basic materials for making explosives. The benzol and toluol could be converted by nitric acid treatment to picric acid and TNT, in whatever quantity was desired. The value of the cracking installations in the world to-day was something like 275 million dollars, and improvements which had been made in the last few years had increased the efficiency of the installations to four times the efficiency of a dozen years ago. Thus, a dozen years ago it would have been necessary to have installed plant of the value of 1,100 million dollars in order to produce the 5 billion odd gallons of gasoline now produced by the cracking process annually. There had not been a greater technical and scientific achievement in the world than the development of the cracking process. It could be so controlled that any quality of anti-knock gasoline could be produced at will, from one with a low anti-knock value to one with a value of the order of benzol and toluol, and which could be used in automobile engines with a compression ratio of 7 or 8 to 1. A great deal of research was being conducted with a view to an even greater

refinement of the process and the production of individual hydrocarbons, and the door was wide open to the most imaginative men in the petroleum industry and in the scientific institutions throughout the world.

M. Bint (France) asked Dr. Ostwald what was the effect of methanol upon automobile and aircraft engine fuels, and how much of it was added.

Dr. Ostwald replied that it had a cooling effect upon the mixture. He used up to about 40 per cent.

Mr. W. A. Whatmough (Great Britain), dealing with the anti-knock problem, said that in the ordinary way chemists and engineers were rather afraid of the ultra-scientific aspects which were predominating in modern science, but he did not see any way of escape therefrom if we were to solve the question of engine knock. In the combustion of hydrocarbons in engines, and, in fact, in any fuel-burning device, the first fundamental was the size and shape of the hydrocarbon molecule. That was known in chemical language as its "stereo chemical configuration," or, in ultra-scientific language, its "orientation in space." Furthermore, it was the surface which that molecule presented to the flow of energy in space that determined whether it was broken up, whether hydrogen was knocked off it, or, in other words, whether thermal dehydrogenation began. The first point of interest in an increase of the anti-knock value of petrol by cracking or by other processes was that ring hydrocarbons were more stable to thermal dehydrogenation than open-chain compounds such as the paraffin hydrocarbons, and that agreed precisely with the effect in engines. A second feature was that the action of anti-knocks was decidedly to slow down combustion rate. Many theories had been put forward with regard to anti-knock action; he was not saying that they did not apply, but they could not be followed to their logical conclusion unless we recognised the existence of molecules in an activated state. The activation was brought about by the action of radiant energy, and the action of anti-knocks was the opposite to activation. In the anti-knock action there was competition by the anti-knock for the activated molecule, which in this instance, at least in his opinion, was activated oxygen. In the first stage the hydrocarbon was activated by losing hydrogen; that hydrogen, in the older language, was called nascent hydrogen, and in the newer language was called monatomic or activated hydrogen. The hydrogen led to the formation of activated oxygen, and the activated oxygen and the hydrogen interacted and formed the nucleus of combustion. In any anti-knock which was successful, such as lead tetraethyl or nickel carbonyl, there was little doubt that the active metal itself was in competition for the activated oxygen, and that that slowed down the rate of combustion. It might appear that this study involved the application of very highly specialised physico-chemical knowledge, but he believed that attention to those points would elucidate many of the questions with regard to anti-knock action. The only theory on detonation so far adanced which had any claim to serious

consideration was that put forward by Egerton, that metals which, at engine temperatures (normally ranging between 400 and 600°C.), produced metal ions which had higher and lower states of oxidation, were likely to be anti-knocks. There was a very serious anomaly manifest in connection with the judging of motor fuels. The present-day tendency was to look upon paraffin hydrocarbons as deleterious and harmful fuels. Actually, they burned faster than the benzene or so-called anti-knock hydrocarbons. In engine practice we wanted fuels to burn as fast as they would burn without producing a knock. Thus, we had the curious anomaly that the paraffin hydrocarbons were the best for burning, but the moment they began to burn too fast they were condemned, and in his opinion the solution of the problem would be reached not so much by inventing anti-knocks as by controlling the rate of combustion so that paraffin hydrocarbons were not burned too fast in the engine, and thus were not allowed to produce knock. That was largely a question of engine design, and there were already very good signs of solving the problem and of being able to run motor fuels of low anti-knock value in really high compression engines—in engines with a ratio of something like 7 to 1, which at present was as high as one wished to go in petrol engines.

Mr. J. Kewley (Great Britain) referred to researches carried out with a view to arriving at a convenient laboratory method of predicting the anti-knock of fuels. As far back as 1919, he said, research was started on the subject. It was then known that hydrocarbons of various types showed great divergence in character in this respect, Attempts were made to examine the effect of pure hydrocarbons, but these were, with few exceptions, only obtainable with great difficulty and at great expense. From the behaviour of many motor fuels, it soon became evident that an analysis of them into aromatics, naphthenes and aliphatics was far from sufficient for deducing the anti-knock value, and one was led to suspect that isomeric hydrocarbons of the same series might display great differences in this respect. Edgar, by his recent preparation of isomeric octanes in sufficient quantity to measure their anti-knock effect, had proved this supposition to be correct. In a similar way he had examined isomeric heptanes and had found that in general the more condensed the molecule, the higher the anti-knock value. In the course of an examination into the question of the so-called dopes, Weerman and Egerton had investigated the spontaneous ignition temperatures of various gasolines, doped and undoped, carrying out the experiment in the presence of air. Harold Moore, in a paper presented before the Institution of Petroleum Technologists in 1920, had dealt rather fully with this subject but had paid more attention to the spontaneous ignition temperature in oxygen rather than in air. Weerman had found that the differences in spontaneous ignition temperatures when using air were more in line with H.U.C.R. than when using oxygen. Weerman and Egerton had found that in every case where the dope raised the H.U.C.R. of the fuel in an engine, it also increased the spontaneous

ignition temperature, but that the converse was not always true. This was easily understood because the action of the dope definitely depended on the temperature at which it had to operate. It was then hoped that the determination of the spontaneous ignition temperature might be used as a measure of the anti-knock value of a fuel. Numerous experiments, however, showed that the relation, though it did exist, was not quantitative, and was useless for purposes of measurement of the anti-knock value. It was possible that under other conditions, a quantitative relation might be established. In the case of Diesel engines, the anti-knock value of a fuel had the reverse effect; fuels which, from the behaviour of the corresponding light fractions, one would expect to have a high H.U.C.R., were liable, owing to delayed ignition, to give rise to bumpy running, It was thought, therefore, that an investigation of the spontaneous ignition temperature of fuels might be useful. The apparatus and method used were similar to that used by Weerman and Egerton. Readings could be repeated to within about 7°C. It was evident that the details of the apparatus and method played a great part, so that there was need for much comparative work and standardisation if the method was to be of value. The following figures obtained with gasolines gave some indication of the range:—

Sp. Ig. Temp. °C.	H.U.C.R.
420	4·2
430	4·9
445	5·1
450	5·4
460	5·3
485	5·6
490	5·85

A number of kerosenes were then tried. These, as would be expected, showed lower spontaneous ignition temperature, but the degree to which they were lower was remarkable. The figures for all those tested ranged between 270 and 300°C. A very aromatic kerosene gave the highest figure, 300°C. and the lowest figure was given by a kerosene of the paraffin type. The difference between the figures, however, was so small that the intermediate members could not be placed in any definite order.

The method was also applied to gas oils. In these cases the differences were greater than in the case of kerosenes.

	°C.
Mid-continent types	285
Mixed base type	305
Highly naphthenic type	370
	380
	385

With fuels containing residues there were difficulties.

The low spontaneous ignition temperature of the kerosenes was noticeable. There was, however, definite evidence that spontaneous ignition temperature did bear a relation to H.U.C.R. The method, if developed, should afford a means of grading not only gasolines, but also gas oils and perhaps Diesel oils. The authors of paper N4 on "Evaluation of Fuels used for Aviation in Germany" had been examining the same method, but were apparently not yet satisfied as to its possibilities. But Dr. Riehm had pointed out the effect of pressure in lowering the spontaneous ignition temperature of fuels, so that this factor must be taken into consideration. The curves given by Dr. Riehm showing the relation between pressure and spontaneous ignition temperature were, however, nearly parallel for hydrocarbon fuels, so that the results obtained at atmospheric pressure might still be sufficiently good for general use.

With regard to the volatility of gasolines, it was interesting to note that a few years ago, owing to the absence of volatile fractions and the natural tendency to abstract as much gasoline from the crude oil as possible, the so-called Navy specification type of gasoline was developed in the United States. This had resulted in the development of a type of engine with a highly heated induction system in order to cope with a fuel of rather low volatility. The development of the natural gas industry, with the production of large quantities of very volatile fractions, had changed this position, so that now there was a distinct trend towards the production of motor spirits containing much more volatile material than formerly.

The inclusion of these volatile fractions as far as possible had a direct advantage in that they had rather high H.U.C.R.'s. A difficulty attendant on the use of such fuels when they had not been well stabilised, and still contained appreciable proportions of propane and larger proportions of butane, was that they might evolve vapour in passing through a carburettor, which was highly heated by conduction from the induction system. Excessive heating of the carburettor, therefore, should nowadays be avoided.

Sir Albert Kitson (Gold Coast) asked for further information as to the development mentioned by Dr. Egloff, by which, it was claimed, rubber could be made synthetically from products of the cracking process, and in sufficient quantities to provide all the motor tyres needed in the world.

Dr. Egloff (U.S.A.) replied that in the United States at present about 200 billion cu. ft. of gas was produced annually by the cracking process. That gas, as well as the distillate, contained butadyene to the extent of 1, $1\frac{1}{2}$ or 3 per cent., according to the temperature and pressure conditions prevailing. On the basis of an output of 200 billion cu. ft. of gas per annum, and assuming a yield of 1 per cent. of butadyene by polymerisation with sodium or ultra-violet light, there would be an annual output of 396 million pounds of a synthesised rubber-like material, which represented a quarter of the quantity of rubber used in the United States.

The quantity of gas produced by the cracking process could be increased tenfold at will within a short time—probably six months would be sufficient to allow of the installation of the units necessary to produce the butadyene in the quantities necessary to supply the world's needs. There were tremendous supplies available, not only of crude oil but of other hydrocarbonaceous material, which could be converted into products suitable for making a synthesised rubber-like material.

Commenting on Mr. Kewley's pessimism as to the quality of the residual oil produced by the cracking process, he said the process could be so controlled as to produce any quality of residual oil required; its viscosity and other properties could be controlled, and its b.s. content could be varied at will from less than 1 per cent. to as much as 30 per cent. A report had just been received from one of the cracking plants in the United States, in which it was stated that one of the units had cracked continuously 35,000 barrels. of a 20 gravity fuel oil, yielding 47 per cent. of finished gasoline and 40 per cent. of a residual oil, containing approximately 1 per cent. b.s. which did not settle out on standing. It was just a question of what it was desired to produce.

Dr. A. E. Dunstan (Vice-Chairman, Great Britain), recalled that in 1916 or 1917 he had read a paper by O. Aschan, who had stated that he was actually cracking Russian mazout, producing methyl butadyene, and making from that many thousand kilogrammes of rubber. The paper was abstracted in the Journal of the Society of the Chemical Industry. Dr. Dunstan agreed that if the methyl butadyene were polymerised there would be produced a rubber-like substance, but he asked if that substance was physically identical with the well-known colloid known as rubber. It must be remembered that rubber was a mixture (probably a colloidal dispersion) of a number of natural products, polymerised diolefines being the major constituent, and the influence of the minor components on the physical qualities of the colloidal solution might cause a great difference between the value of the natural and the synthetic material.

Dr. Egloff (U.S.A.) replied that in 1912 the Germans attending the international convention in America had taken with them tyres made of such substances, which had been used on cars for distances of something like 12,000 miles, and which exhibited all the wearing properties of ordinary rubber. It would be noted that in his remarks on this question he had carefully referred to a "rubber-like material," and he was certain that methyl butadyene, isoprene, butadyene itself or other derivatives, if sufficient research were applied to them, could be made to produce a rubber-like material which would have good wearing qualities, and which would enable automobiles to be operated in a practical manner without shock to the nerves.

Sir Albert Kitson (Gold Coast), proposing a vote of thanks to the Chairman, the Vice-Chairman, the General Reporter and all who had contributed to the discussion, said it was to be hoped that

the development of the process referred to for producing this rubber-like material would not result in crushing the great rubber plantation industry which had been created in various parts of the world. It was interesting to have this information from America, because America had large plantations of her own.

The vote of thanks was carried with acclamation.

THE CHAIRMAN, responding to the vote of thanks, paid a tribute to Dr. Dunstan, who had done the greater part of the work in connection with the proceedings of Section F. As a member of the Finance Committee, the Chairman expressed appreciation of the work done by the Technical Committee, and said he gathered, from the trend of the discussion, and from the fact that so few speakers had taken part in it, that a thorough presentation of the position in regard to liquid fuels was made in the papers contributed. He concluded by asking those present not to take too seriously all that Dr. Egloff had said.

DR. DUNSTAN replied briefly to the vote of thanks.

Note. During the discussion on Section W, the Chairman permitted a resolution to be put in connection with Section F.

HERR F. ZUR NEDDEN (Germany) said that the subject on which he wished to address the meeting was entirely outside the discussion that was just taking place; it dealt with the subject of liquid motor fuel and ought to have been put before Section F on the afternoon of September 25. It was found impossible, however, to get the motion in shape to be placed before that Section and therefore it had been arranged with the Technical Committee to put the motion before the meeting that afternoon, with the object of getting it formally passed and placed before the final meeting of the Conference on Friday, October 5. There had been some advantage in the fact that it had not been possible to place the motion before Section F somedays previously, because in the meantime it had been possible to get the support of various big industries dealing with oil and various nations, and to put the motion in such a form as to meet with their approval. The subject of the motion was the necessity for a closer understanding throughout the world of the real meaning of the denominations in use for the various types of motor fuel. As had been pointed out in the paper by Mr. Lubbock, the words "fuel oil" covered an immense variety of petroleum products very rarely appreciated by the average user, and in addition to that there would come into existence in the near future another variety of synthetic oils. There was also a great deal of confusion even among experts between the expressions "light" and "heavy" oils, residual oil, furnace oil and so on. In Great Britain oil fuels were marketed in three distinct categories, namely, gas oil, Diesel oil and fuel oil, and probably in other countries it was very similar. These denominations, in reality, overlapped. All three could be looked upon as fuel oil; gas oil made an excellent fuel for Diesel engines; fuel oil could be used advantageously in certain types of Diesel engines; and Diesel oil was frequently used for certain types of burners. At first sight, a classification according to gravity would

eliminate this uncertainty, but other characteristics of oils also came in which rendered some better definition desirable. The problem was how to characterise scientifically these various types of oil, because it was apparent that it would not be sufficient to characterise them on the basis of one characteristic alone, such as gravity. At present there was no international standard, and all those concerned had agreed upon the necessity to settle upon some standard, if possible, in order that those who carried out comparative tests would be able to make their comparisons really effective. With this object in view he proposed the following resolution:—

Whereas the Fuel Conference of the World Power Conference, assembled at London in September, 1928, has evidenced a universal desire among fuel experts from all parts of the world to arrive at some international understanding regarding the methods of defining the characteristics of liquid motor fuel—

And whereas it is believed that great benefit for the industries and the pertinent branches of technical science will accrue from such international action—

Be it resolved that the International Executive Council of the World Power Conference be instrumental in paving the way to such international understanding.

Dr. Coleman (Great Britain) seconded the resolution, which was carried unanimously.

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